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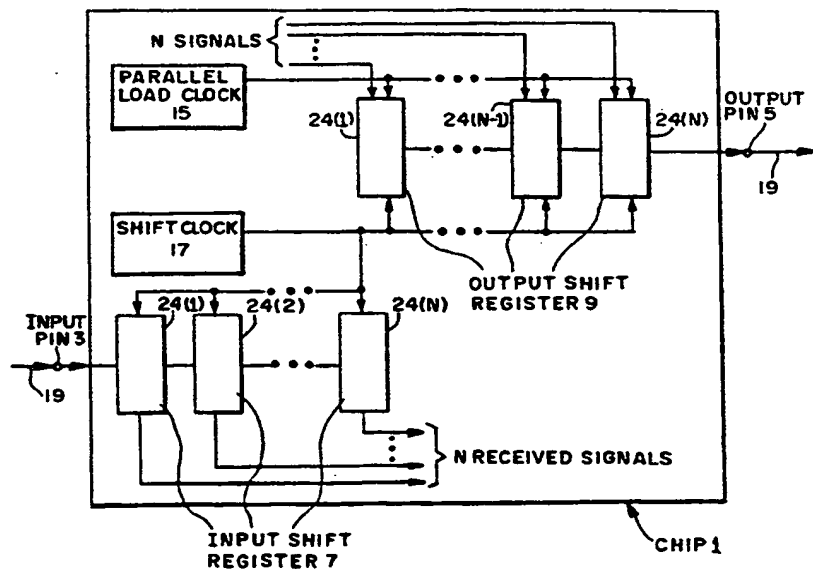
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(54) Title: MULTICHIP IC DESIGN USING TDM



## (57) Abstract

In a multichip integrated circuit module (4), the number of effective input/output pins (3, 5, respectively) is increased by using techniques of TDM (time division multiplexing). A first chip (1) has at least one output shift register (9). A second chip (1) has at least one input shift register (7). Interconnection wires (19) couple the output shift registers (9) and the input shift registers (7). Means (15) are provided for loading data in parallel to the output shift registers (9). Means (17) are provided for sequentially shifting data through the output shift registers (9) over the interconnections (19) and into the shift input registers (7). Embodiments of the invention are described for use in conjunction with bi-directional pins (25), tri-state output drivers (21), and asynchronous logic (18).

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Description  
MULTICHIP IC DESIGN USING TDM

Field of the Invention

This invention pertains to the field of designing circuits having a plurality of integrated circuit (i.c.) chips, said design using techniques of TDM (time division multiplexing).

Description of Background Art

Dobbelaere et al., "Field Programmable MCM Systems -- Design of an Interconnection Frame", IEEE 1992 Custom Integrated Circuits Conference, pp. 4.6.1-4.6.4, addresses the same problem addressed by the present invention -- increasing the number of effective input/output pins in a multichip i.c. module -- by different techniques. The reference teaches programming a matrix at the corner of each chip to determine the interconnects among the inputs and outputs. The chips are FPGA's (field programmable gate arrays). The reference does not disclose the use of shift registers or TDM.

"Programmable Interconnect Architecture", Aptix Corporation Technology Backgrounder, Nov. 1991, pp. 1-14, and an Aptix press release dated January 1, 1992, describe use of an areal grid to preserve the ability to change the interconnects among a set of integrated circuit chips in applications where a logic is being implemented onto a set of multiple i.c.'s. These references do not disclose techniques of TDM. Shift registers are used, but only to determine which i.c.'s get connected to each other. The present invention uses shift registers to convey signal information from chip to chip.

U.S. patent 5,036,473 uses dedicated FPGA's solely to determine what active FPGA's get connected to which others. The reference discloses the use of software to drive and observe signals, but does not disclose the use of shift registers or TDM.

U.S. patent 5,109,353 discloses an array of programmable gate elements for emulating electronic

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circuits and systems. It does not disclose the use of shift registers or TDM.

"Handbook of Hardware Modeling", Logic Modeling Systems Incorporated, February 1992, describes the use of software to drive and observe signals in a multichip module. Techniques disclosed in this reference can be used in conjunction with the invention described herein.

"Computer-Aided Prototyping", Quickturn Systems, Inc., 1991, pp. 1-4, discloses partitioning logic for a set of interconnected FPGA's and providing software stimulus to capture and observe the response. There is no disclosure of shift registers or TDM. This technology is further described in "FastForward", LSI Logic, September 1991, and "MARS Product Overview", PiE Design Systems, Inc. Similar technology is described in three press releases by InCA Integrated Circuit Applications: "InCA 'Virtual ASIC' Emulation System supports Xilinx 4000 family FPGAs", June 8, 1992; "Virtual ASIC, Automatic ASIC Emulation from InCA", 1991; and "Concept Silicon partitions your design onto multiple FPGAs".

Disclosure of Invention

The present invention is a multichip integrated circuit module (4) comprising at least two integrated circuit chips (1). The first chip (1) has at least one output shift register (9). The second chip (1) has at least one input shift register (7). Interconnections (19) couple the output register(s) (9) and the input shift register(s) (7). Means (15) are provided for loading data in parallel to the output shift register(s) (9). Means (17) are provided for sequentially shifting data through the output shift register(s) (9) over the interconnections (19) and into the input shift register(s) (7).

Brief Description of the Drawings

These and other more detailed and specific objects and features of the present invention are more fully disclosed in the following specification, reference being had to the accompanying drawings, in which:

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Figure 1 is a sketch of an embodiment of the present invention in which an integrated circuit chip 1 uses at least one input shift register 7 and one output shift register 9.

5        Figure 2 is a sketch showing how the techniques of the present invention reduce the number of interconnection wires 19 among chips 1.

10       Figure 3 is a sketch of an embodiment of the present invention in which the number of stages 24 in an input shift register 7 and output shift register 9 can be reduced by one.

Figure 4 is a sketch of a chip 1 using tri-state output drivers 21.

15       Figure 5 is a sketch of an embodiment of the present invention in which two output shift registers 9 are used in conjunction with a single output driver 21.

Figure 6 is a sketch showing a plurality of tri-state output drivers 21, each having a common gating signal 23.

20       Figure 7 is a sketch showing how a single output shift register 9 can be used when the output drivers 21 have a common gating signal 23.

25       Figure 8 is a sketch showing the use of bi-directional pins and a plurality of tri-state output drivers 21 having a common gating signal 23.

Figure 9 is a sketch showing how a single bi-directional pin 25 can be used when a plurality of tri-state output drivers 21 have a common gating signal 23.

30       Figure 10 shows a chip 1 having a plurality of bi-directional pins 25, each coupled to an output driver 21 that has a different gating signal.

Figure 11 shows a single pin 25 equivalent to the embodiment depicted in Figure 10.

35       Figure 12 shows an embodiment of the present invention in which asynchronous logic 18 is employed.

Figure 13 shows an embodiment of the present invention in which a plurality of output shift registers 9 are daisy chained together.

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Figure 14 shows an embodiment of the present invention in which a plurality of test shift registers 12 are multiplexed together.

5 Figure 15 shows an embodiment of the present invention in which the TDM sequence must be applied twice.

Figure 16 shows an embodiment of the present invention in which an interconnect 19 couples two chips 1.

Figure 17 shows how the interconnect 19 of Figure 16 can be reconfigured by reprogramming the first chip 1(1).

10 Figure 18 shows a single interconnect 19 coupling four chips 1.

Figure 19 shows how the interconnect 19 of Figure 18 can be reprogrammed by reprogramming the source chip 1(1).

15 Figure 20 shows an embodiment of the present invention in which an interconnect wire 19 couples two chips 1.

Figure 21 shows how the interconnect 19 of Figure 20 can be reprogrammed by adding a new signal S3 to the source chip 1(1).

20 Figure 22 shows an embodiment of the present invention in which the number of stages 24 in an input shift register 7 can be reduced by one.

#### Detailed Description of the Preferred Embodiments

25 A major purpose of this invention is to increase the effective number of input/output (I/O) pins 3,5 on integrated circuit chips 1 within a module 4 that comprises a plurality of said chips 1. The invention can be thought of as creating a number of virtual I/O pins 3,5 that is greater than the number of actual pins 3,5.

30 The invention also eases pressures on the system designer when the number of interconnect wires 19 on the module 4 is limited. Further, the invention enhances the reconfigurability of signal flow across chips 1.

35 An example where the invention is useful is in the design of a system 4 in which there is a need to fit a given amount of logic, which may be provided in the form of a netlist, into one or more of the chips 1. Normally, said chips 1 come with a fixed number of I/O pins 3,5 that are used for interconnections 19 among the chips 1.

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The limited number of I/O pins 3,5 can greatly reduce the efficiency of utilizing the chips 1, and in some cases make the task of fitting the logic into the chips 1 extremely difficult.

5       The module 4 can be a production module, in which the chips 1 are executable and application-ready. Alternatively, module 4 can be a prototype module, in which the chips 1 are experimented with by the designer to create a system design. Changes in such a prototyping  
10       environment are typically done by a combination of hardware and software changes. Alternatively, module 4 can contain some production chips 1 and some programmable chips 1.

15       Chips 1 are any chips for which the user has control over the contents, such as FPGA's (field programmable gate arrays), non-field-programmable gate arrays, custom i.c.'s, semi-custom i.c.'s (application specific integrated circuits), and standard cell i.c.'s. FPGA's are normally preferable, because of their flexibility.

20       The present invention makes use of techniques of TDM (time division multiplexing or time domain multiplexing). The execution of the system embodied in module 4 takes longer because of this, but in many applications this is of no concern. The TDM process is  
25       transparent to the operation of the logic embodied in module 4.

30       Typically the TDM is implemented by shift registers 7,9, as illustrated in Figure 1. Each input pin 3 and each output pin 5 on a chip 1 is assigned a dedicated shift register, 7,9, respectively. The number of stages  
35       24 in a shift register 7,9 is referred to as N. N is any positive integer greater than or equal to 2, and could be typically between 2 and 5. Preferably, N is the same for all shift registers 7,9 on a chip 1. If N were not the same, a separate shift clock 17 would be needed for each  
different value of N. In the chip 1 illustrated in Figure 1, the value of N is the same, and therefore there is but one shift clock 17.



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Each chip 1 can have a plurality of input pins 3 and a different number of output pins 5. The different chips 1 on a module 4 can have different numbers of input pins 3 and output pins 5.

5       The individual stages 24 of the shift registers 7,9 can be, for example, flip-flops, edge triggered latches, and pairs of polarity hold latches. When polarity hold latches are used, a pair of shift clocks 17 is required for use with the corresponding shift register 7,9.

10       The shift register 9 attached to an output pin 5 is referred to as an output shift register (OSR) 9, and functions as N virtual output pins 5. N internal signals from within the chip 1 can be loaded into the OSR 9 in parallel by means of activating a parallel load clock 15  
15       associated with the OSR 9. These signals are then serially shifted out of the OSR 9 over the corresponding output pin 5 using the shift clock 17 associated with said OSR 9. The signals travel over interconnection wires 19 to other chips 1 that need to receive the  
20       signals.

Similarly, the shift register 7 attached to an input pin 3 is referred to as an input shift register (ISR) 7, and functions as N virtual input pins 3. It can receive serially N signals from a board interconnect 19 through  
25       the associated input pin 3 by means of the shift clock 17 that is connected to said ISR 7. The received signals can then simultaneously be applied inside the chip 1 using their stored states within the stages of the ISR 7. No special clock is needed to unload the signals from  
30       the ISR 7, because once these signals are in the ISR 7, they are visible to the logic within the chip 1.

Preferably, a single parallel load clock 15 and a single shift clock 17 are used for all the ISR's 7 and OSR's 9 on the board 4.

35       Preferably, the OSR's 9, ISR's 7, and attendant parallel load and shift clocks 15, 17 are customized within peripheral regions of the gate arrays 1. Alternatively, the OSR's 9 and ISR's 7 are fabricated from logic normally present on the gate arrays 1.

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Figure 2 illustrates how the invention minimizes the number of interconnect wires 19 among chips 1,2 and minimizes the number of I/O pins 3,5 within a chip 1. Figure 2 illustrates the interconnections of OSR 9 within a source chip 1 and three ISR's 7 residing within three target (sink) chips 1. The target chips 1 could be identical or different in a hardware sense. A single interconnect wire 19 couples the chips 1. Three signals S1, S2, and S3 from the source chip 1 are conveyed to the three sink chips 1. If the TDM and shift register technique were not used, three interconnects 19 would be required. The interconnect wire 19 can be thought of as a TDM bus which bundles in the time domain the three signals S1, S2 and S3. Said TDM bus 19 is visible to all three sink chips 1.

As illustrated in Figure 2, not all of the three signals need to be used in each sink chip 1. (The signals within the sink chips 1 are primed for notational purposes.)

The TDM process described herein is transparent to the intended logic design. This transparency can be achieved in different ways, depending upon the degree of transparency needed. For example, if all chips 1 on the module 4 are synchronously clocked (which is preferable), the following two-step TDM process can be used, at a safe time after the application of each pulse from the system clock (not illustrated). The safe time is that amount of time needed for all of the signals in the logic to achieve a steady state, i.e., when the intended design has been programmed into the chips 1.

Step 1. The parallel load clock 15 (which is preferably a single clock applied to all output shift registers 9 on the board 4) is applied to effect a parallel capture of signals into all of the OSR's 9 on all the chips 1.

Step 2. Using the shift clock 17 (preferably a single clock used by all the ISR's 7 and OSR's 9 on all the chips 1), the contents of all of the OSR's 9 are shifted into the target ISR's 7 via the interconnects

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19. This shifting process involves N applications of shift clock 17 to all of the chips 1.

Exceptions to the above scheme exist for various reasons, such as: (1) Certain I/O pins are  
5 bi-directional pins 25 (see Figure 8). Such bi-directional pins 25 could be left unmodified. Signals involving such pins 25 are not affected by the above two steps. (2) Inputs 3 that receive direct clock signals (as opposed to data signals) do not require the use of an  
10 ISR 7. Such would be undesirable, because it would cause the clock to jiggle. Similarly, output pins 5 that carry clock signals going to other chips 1 do not require the use of OSR's 9. Clock signals cannot be transferred across chips 1 using TDM without significant impact to  
15 the intended logic. As such, it is not desirable to use such techniques for I/O pins 3,5 that carry clock signals.

Figure 12 shows that if the logic being prototyped is asynchronous, an additional latch 29 is needed for each ISR 7 stage 24 that drives a piece of asynchronous  
20 logic 18. Such a latch 29 is a voltage level or logic level sensitive latch that receives its data from an ISR 7 stage output and is clocked by yet another clock called the P clock 27. P clock 27 is shared among all chips 1 that have asynchronous logic. The function of this added  
25 latch 29 is to screen the shifting of the ISR 7 from the asynchronous logic 18. P clock 27 is pulsed once after the completion of the two usual TDM steps, described earlier, that are used to effectuate the transfer of signals across chip 1 boundaries using TDM. As shown in  
30 Figure 12, some of the stages 24 of the ISR 7 can drive synchronous logic 16, and others of the stages 24 can drive asynchronous logic 18.

As illustrated in Figures 13 and 14, multiple OSR's 9 can be connected into one daisy-chained composite "test  
35 shift register" (TSR) 12 on each chip 1 to facilitate the observation of the captured signals externally by shifting out the TSR 12. All of the observation can be performed at the output of pin 5(M). These observed signals can be used for debugging the prototype hardware,

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depending upon the availability of extra board 4 logic and pins 3,5. The contents of the TSR 12 can then be reloaded from the output 5(M) of the TSR 12 to the shift register data input 3 on the same chip 1 if it is desired to continue with the operation of the hardware. A preferred way of accomplishing this reloading is to make a connection on the chip 1 itself from output 5(M) to input 3, thereby creating a circular shift register.

The set of TSR's 12 can be multiplexed to be observable at the output 10 of the board 4 as illustrated in Figure 14. Multiplexer select signals 14 control the selection of the individual TSR 12 outputs by multiplexer 8. The input to all the TSR's 12 is injected via board input 6. The scheme depicted in Figure 14 is useful when there are more chip output pins 5 than the designer wants to observe than there are available board output pins 10.

Since the OSR's 9 are usable for debugging purposes, the designer can choose to provide extra, initially unused, stages 24 within some OSR's 9. These stages 24 are then available to be used for observing internal signals that the hardware designer may not have thought about earlier, for example, by changing the programming on the chip 1 to look at these stages 24.

It is possible to reconfigure the interconnects 19 among the chips 1 by sending a different set of signals on each interconnect 19 than was previously intended. When combined with the internal reconfigurability of the FPGA 1 itself, a powerful new type of reconfigurability is thereby created. Figure 14 shows a module 4 with a number of FPGA's 1 and set up for using TDM. To achieve a reprogrammable board 4, it is required that one must be able to reprogram both the logic on the chips 1 as well as the interconnects 19. The on-chip logic is already rather reprogrammable through the use of the FPGA's 1. To reprogram the interconnects 19, an FPGA 1 can be used as a programmable interconnect chip as in U.S. patent 5,036,473, cited above; or a programmable interconnect chip as described in the Aptix references cited above can be used. Alternatively, several programmable

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interconnect chips 1 may be used. A limited reprogrammability of interconnects is described in Figures 16-21.

Figure 16 shows three signals, S1, S2, S3, TDM'ed  
5 between chips 1(1) and 1(2). By reprogramming the first FPGA 1(1), the manner in which the three signals S1, S2, S3 connect can be changed, as shown in Figure 17. In effect, the connections 19 between the two chips 1 have been rewired.

10 Figure 18 shows four chips 1 with signals S1, S2, S3 connected as shown. By reprogramming the first chip 1(1), as shown in Figure 19, signal S3 crossing between chips 1(1) and chips 1(4) is changed to S4.

In Figure 20, two interconnected chips 1 are shown.  
15 Figure 21 shows how a signal can be added to the interconnect 19 just by reprogramming the individual chip 1(1) and not touching the interconnect 19.

The flexibility described herein results from chip 1 being able to reprogram a number of signals that are  
20 TDM'ed across to other chips 1. Traditional techniques limit the reprogrammability to a single signal.

Once the value N is fixed for a given system 4, the total number of signals that can be moved across the chip 1 boundaries is predetermined. The total number of  
25 signals movable is N multiplied by the number of unique interconnect wires 19 on the board 4. It is apparent that by increasing N, a capacity greater than what is initially needed for the total number of signals can be achieved. The additional capability is usable for  
30 greater flexibility in reconfiguring the interconnects 19.

Theoretically, it is possible to accomplish all interconnections between any two chips 1 by using two interconnect wires 19 between them: one to carry signals flowing in one direction, and the second to carry signals  
35 flowing in the opposition direction. In this extreme situation of maximum multiplexing, the shift registers 7,9 must have an N greater than or equal to the larger of the number of the input signals and the number of the

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output signals on any single chip 1. (One signal is associated with each stage 24 of a shift register 7,9.)

The techniques of the present invention can be selectively applied to areas of logic that are considered susceptible to change or require use of TDM to accommodate the number of signals that need to traverse across chip 1 boundaries. As such, ISR's 7 and OSR's 9 need not be placed on all qualifying I/O pins 3,5. Instead, if there are insufficient resources on the chip 1, the ISR's and OSR's 7,9 may be deployed only on enough I/O pins 3,5 to allow adequate signal flow through the chips 1. It should be noted that an interconnect 19 must have either ISR's 7 and OSR's 9 on all terminals of that interconnect 19, or else must have no ISR's 7 or OSR's 9 at all.

When the chips 1 are FPGA's, it is possible to make engineering changes to prototype hardware 4 by reprogramming the affected FPGA's 1 to (1) change the logic realized by certain FPGA's 1 and/or (2) modify the effective interconnects 19 by capturing different signals into one or more of the OSR's 9 and/or (3) change the signals that are made observable by capturing them into unused stages 24 of OSR's 9.

Figure 22 shows an optimized version of the scheme in Figure 2. Here, the contents of the OSR 9 can be made observable, while reducing the number of stages 24 in an ISR 7 by one. In this embodiment, the state of the last stage 24 of an OSR 9 is used as a substitute for the eliminated stage 24 of an ISR 7.

In certain prototyping situations, it may not be necessary to observe the contents of the OSR's 9. In these cases, the number of stages 24 needed in an ISR 7 and OSR 9 can be reduced by one, corresponding to the stage 24 the system designer does not need to observe. This reduction is achieved by using the scheme depicted in Figure 3. Figure 3 shows how N equals 2 can provide the capability to multiplex three signals across a single interconnect 19. In this embodiment, the final state of the interconnect 19 after application of the TDM sequence

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is used as one of the multiplexed signals for the sink chip 1(2). In contrast, the scheme depicted in Figure 2 does not have the sink chips 1 dependent upon the final state of the interconnect 19, but only on the states of the ISR's 7.

The scheme depicted in Figure 1 uses ISR's 7 and OSR's 9 to multiplex signals across chip 1 boundaries. Such a TDM sequence serves to transfer signals once across an interconnect 19. However, if there is a logic path that is not interrupted by a latch or other sequential logic (other than ISR's 7 and OSR's 9) and spans more than two FPGA chips 1, then the TDM sequence needs to be repeated. The total number of TDM sequence applications required is equal to the number of distinct board level interconnect wires 19 that are included in the logic path. Figure 15 shows a logic path of combinational logic 22 that spans two board level interconnect wires 19(1) and 19(2). There are no latches other than ISR's 7 and OSR's 9 in the path. As such, the TDM sequence needs to be applied twice to move the signal through the three chips 1. Notice that ISR's 7 and OSR's 9 force the use of TDM. Without ISR's 7 and OSR's 9, the signal from chip 1(1) to chip 1(2) to chip 1(3) would flow without any clocking.

The techniques of the present invention can be extended to bi-directional pins 25 and/or three state output drivers 21. (See Figure 4). Such a driver 21 typically has outputs of logical zero, logical one, and high impedance.

Buses 19 generally employ tri-state drivers 21 to allow multiple source chips 1 onto a single wire. Such buses 19 are intended by the designer to achieve efficient interconnects between a multitude of source chips 1 and some number of sink chips 1. Generally, one source chip output driver 21 is active while others are in a high impedance state, so that one source chip output driver 21 is driving all receivers in the bus 19. The architecture shown in Figure 1 cannot be employed directly in such a case. Figure 4 shows N output pins 5,

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with a tri-state driver 21 on each pin 5. The OSR 9 scheme of Figure 1 will not work here, because the high impedance state cannot be transmitted via an OSR 9 and an ISR 7. Instead, the scheme shown in Figure 5 needs to be employed. It should be noted that this scheme uses two OSR's 9 instead of one: the first OSR 9(1) to capture the N gating signals and the second OSR 9(2) to capture the N data signals. Output driver 21 sees the corresponding gate-data combination as the OSR's 9 are shifted out. Thus, output pin 5 sees the gated output from output driver 21. The generated TDM sequence of signals on output pin 5 combines with similarly generated TDM sequences from other output pins 5 that are connected with this first output pin 5.

Figure 6 shows N output pins 5 with high impedance drivers 21 that share a common output gating signal 23. Signal 23 either produces a high impedance on the outputs of drivers 21 or else transmits the input signals to the outputs. Figure 7 shows a corresponding single pin architecture that avoids the use of two OSR's 9 but still places output driver 21 between the single OSR 9 and the output pin 5. The use of two OSR's 9 is avoided because of the presence of the common gating signal 23.

Figure 8 shows a typical N bi-directional pin 25 configuration with a common output gating signal 23. In Figure 8, the same pin 25 is used to both output a signal from the chip 1 as well as to receive signals from the outside. To achieve a single pin 25 architecture for TDM of the N signals, the scheme of Figure 9 is employed. In Figure 9, the architecture of Figure 7 is used to feed the outputs of the N drivers 21, and a single ISR 7 is used for the N input signals as in the Figure 1 embodiment.

Figure 10 shows N bi-directional pins 25, each with a different gating output signal. The single-pin 25 architecture equivalent for TDM of the N signals uses the scheme shown in Figure 11. In Figure 11, the architecture of Figure 5 is employed for the N output



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drivers 21, and a single ISR 7 is applied to the N input signals as in the Figure 1 embodiment.

Personalization instructions are injected into module 4, e.g., by techniques described in U.S. patent  
5 5,109,353 cited above. More than one logic design can be introduced into the module 4 by different personalization instructions. Software that is intended to provide automatic or interactive partitioning of the intended system design, such as Concept Silicon from InCA cited  
10 above, can exploit the knowledge of the existence of ISR's 7 and OSR's 9 to help pack more logic into each of the programmable chips 1 and/or to minimize the number of interconnection wires 19.

The software is executed on a computer external to  
15 module 4, e.g., a workstation. The software can be standalone (not physically coupled to module 4) software that exploits the hardware architecture of the module 4 as introduced by the invention. Alternatively, there can be physical coupling between the software and the module  
20 4, e.g., the computer on which the software is executed can have an electrical connection to the module 4, over which the personalization created by the software is downloaded into the module 4.

The benefit of minimizing the number of chips 1 is  
25 obvious. The benefit of minimizing the number of interconnects 19 is significant. If the prototype board 4 is intended to utilize Aptix-type programmable interconnect chips, minimizing the number of interconnects 19 will reduce the number of Aptix  
30 components needed to achieve programmable interconnects. Either the software is told the number of virtual I/O's 3,5 rather than the actual number; or else the software is told all about the ISR's 7 and OSR's 9 so that it will take this information into account when it does the  
35 partitioning. The programmable interconnect chip does not always need to be changed. Rather, ISR's 7 and/or OSR's 9 are placed on the chips 1 to which the programmable interconnect chip is connected, thereby enhancing the programmable interconnect chip.

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Combining the use of the present invention with the use of one or more programmable interconnect chips can allow the board 4 designer the flexibility of creating additional interconnects 19 among chips 1. Programmable  
5 interconnect chips are used to interconnect among two or more I/O pins 3,5. These I/O pins 3,5 could also have ISR's 7 and OSR's 9 on board the chip 1, thus providing a greatly increased number of programmable interconnects.

The configuration of the prototype board 4 is  
10 changed by a combination of hardware and software. For hardware changes, interconnects 19 are reprogrammed, FPGA's and/or programmable interconnect chips 1 are reprogrammed, FPGA's 1 are added or subtracted, and connections are obliterated using lasers. For software  
15 changes, software other than the partitioning software is used to, e.g., reprogram the Aptix chip(s) 1.

The above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. The scope of the  
20 invention is to limited only by the following claims. From the above discussion, many variations will be apparent to one skilled in the art that would yet be encompassed by the spirit and scope of the invention.

What is claimed is:

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Claims

1. A multichip i.c. module comprising:  
at least two integrated circuit chips, a first  
chip having at least one output shift register and a  
5 second chip having at least one input shift register;  
interconnections coupling the output shift  
register(s) and the input shift register(s);  
means for loading signals in parallel to the  
output shift register(s); and  
10 means for sequentially shifting signals through  
the output shift register(s) over the interconnections  
and into the input shift register(s).
2. The multichip i.c. module of claim 1 wherein  
all chips are clocked synchronously.
- 15 3. The multichip i.c. module of claim 1 wherein at  
least one chip contains asynchronous logic, said chip  
comprising an input shift register that is coupled to  
said asynchronous logic via a polarity hold latch;  
wherein:  
20 said polarity hold latch is clocked by a P  
clock.
4. The multichip i.c. module of claim 1 wherein at  
least some of the chips are gate arrays from the set  
comprising FPGA's and non-field-programmable gate arrays.
- 25 5. The multichip i.c. module of claim 4 wherein  
the output shift register(s), the input shift  
register(s), and associated clocking are customized  
within peripheral regions of the gate arrays.
6. The multichip i.c. module of claim 4 wherein  
30 the output shift register(s) and input shift register(s)  
are fabricated from logic normally present on the gate  
arrays.
7. The multichip i.c. module of claim 1 wherein  
the means for loading signals is a parallel load clock.
- 35 8. The multichip i.c. module of claim 1 wherein  
the module is a production module containing executable  
chips.

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9. The multichip i.c. module of claim 1 wherein the multichip module is a prototype module containing at least some experimental chips.

5 10. The multichip i.c. module of claim 1 further comprising software means to partition logic among the chips, said software means exploiting information concerning the particular architecture of the module.

11. The multichip i.c. module of claim 1 wherein said module contains a programmable interconnect chip.

10 12. In a multichip i.c. module comprising at least two integrated circuit chips, each chip having a plurality of I/O pins, said module having inter-i.c. connection wires interconnecting said pins, a method for increasing the effective number of I/O pins, said method  
15 comprising the steps of:

time division multiplexing signals at an output pin of a first chip; and

sending said signals over a connection wire to an input pin of a second chip.

20 13. The method of claim 12 wherein all chips are clocked synchronously.

14. The method of claim 12 wherein said step of time division multiplexing comprises the substeps of:

25 parallel loading signals into an output shift register within a first chip; and

accessing signals in parallel from an input shift register within a second chip.

30 15. The method of claim 14 wherein at least some of the chips are gate arrays from the set comprising FPGA's and non-field-programmable gate arrays.

16. The method of claim 15 wherein the output shift register(s) and input shift register(s) are customized within peripheral regions of said gate arrays.

35 17. The method of claim 15 wherein the output shift register(s) and input shift register(s) are fabricated from logic normally present on said gate arrays.

18. The method of claim 14 wherein the input and output shift registers comprise stages fabricated from

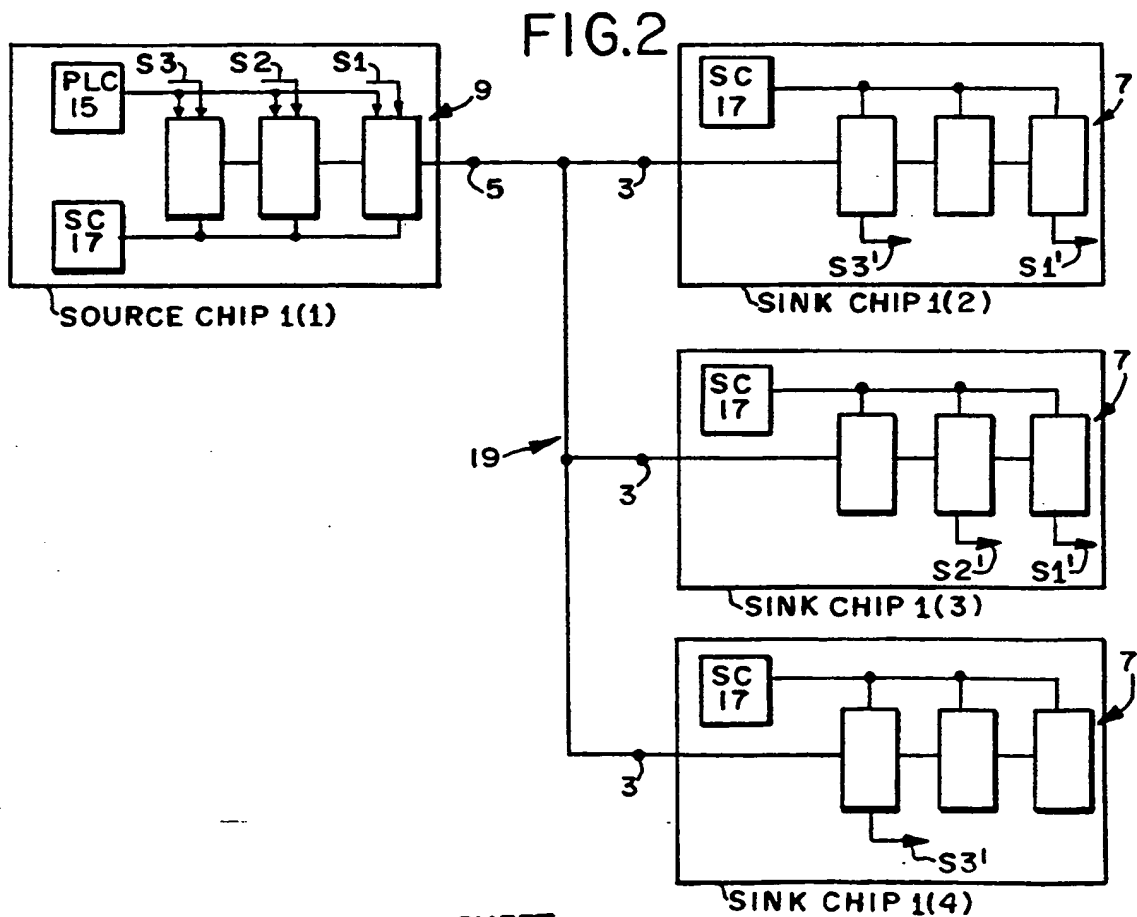
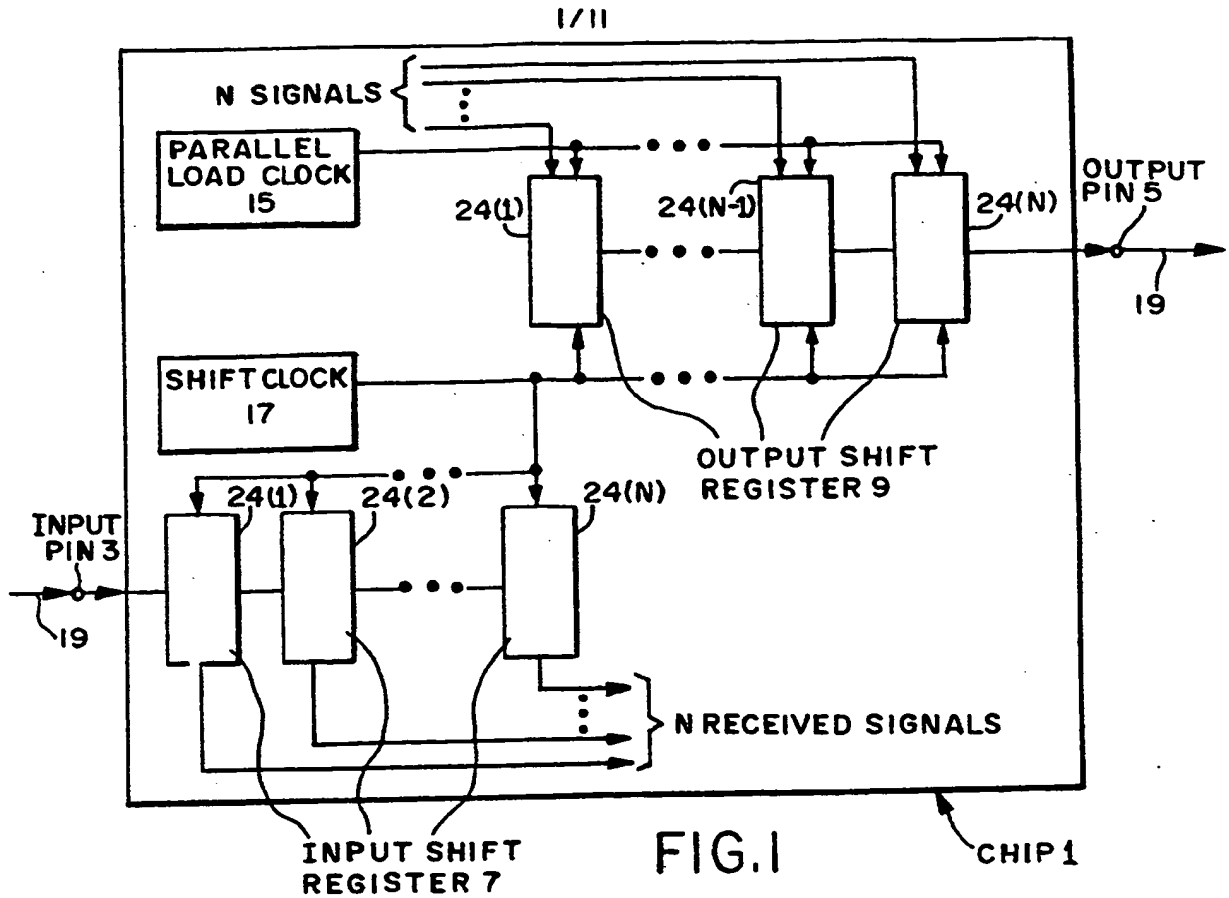
- 18 -

items from the group of items comprising flip-flops, edge triggered latches, and pairs of polarity hold latches.

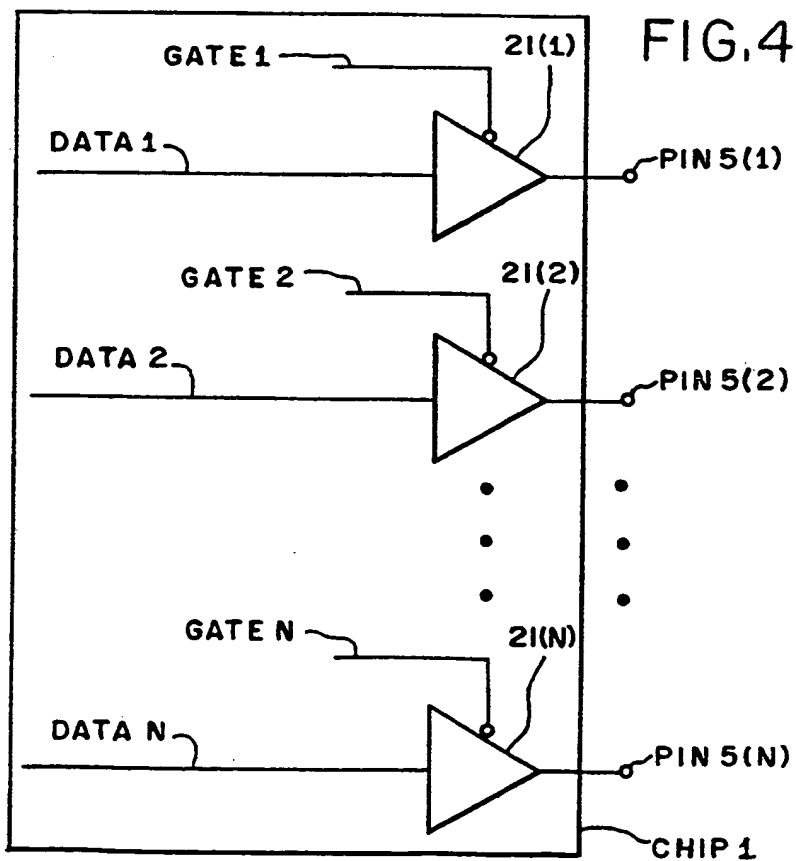
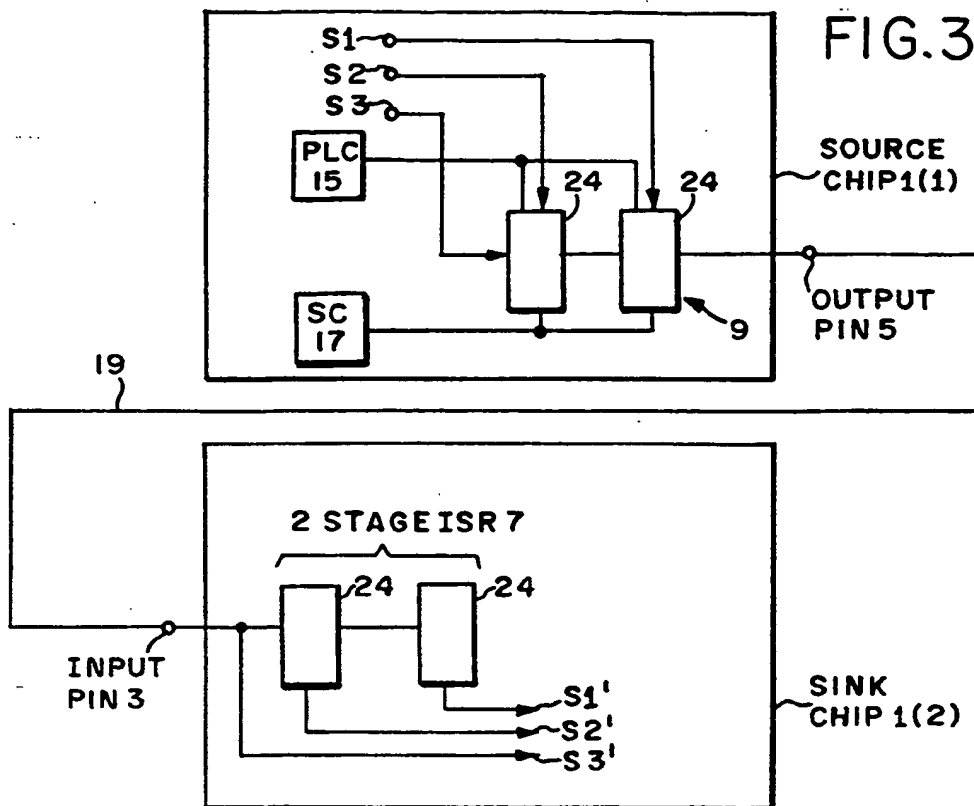
19. The method of claim 18 wherein one of said stages is reserved for debugging purposes.

5           20. The method of claim 12 further comprising the additional step of determining a logic design for the module by use of partitioning software that exploits information concerning the particular architecture of the module.

10           21. The method of claim 12 further comprising the step of observing said signals at said output pin for test purposes.



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FIG. 5

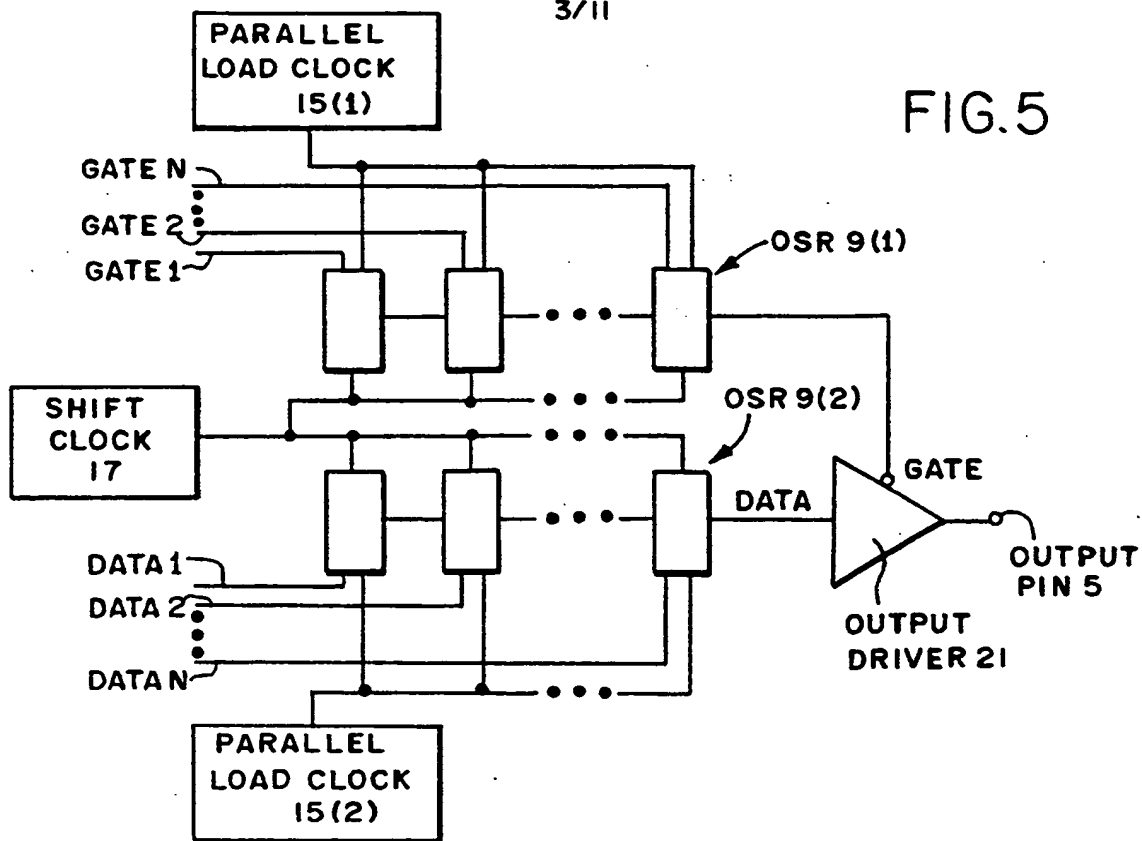
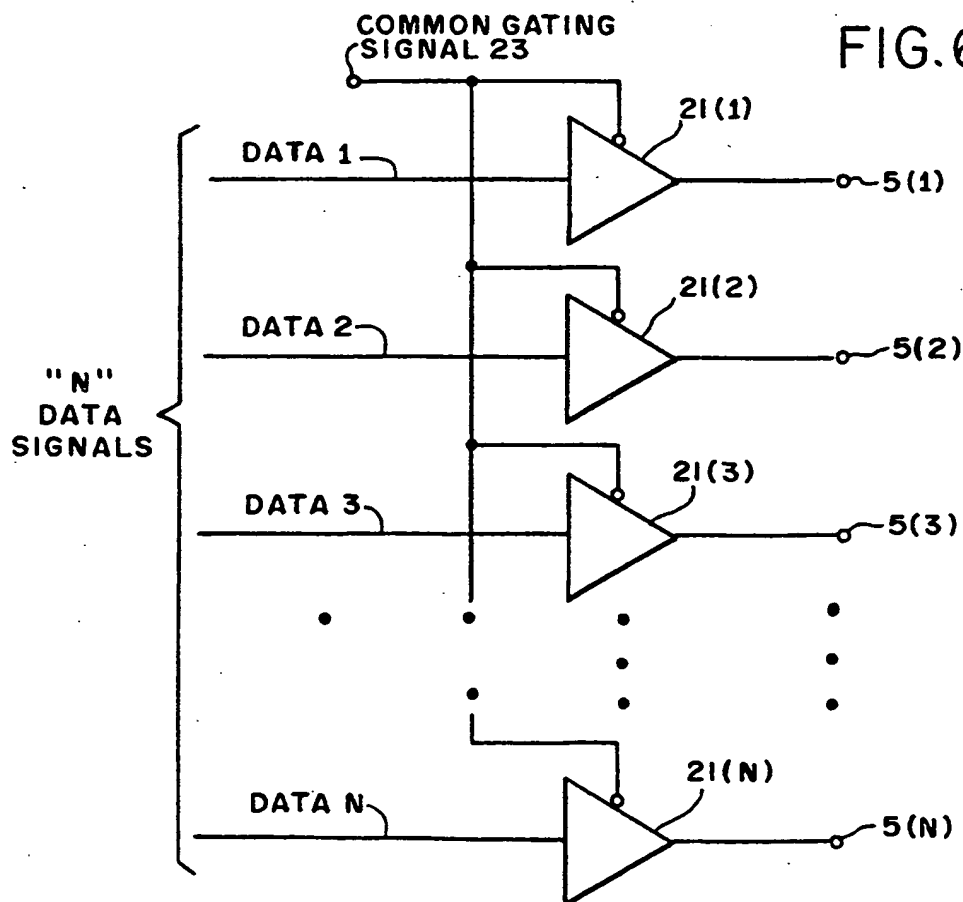
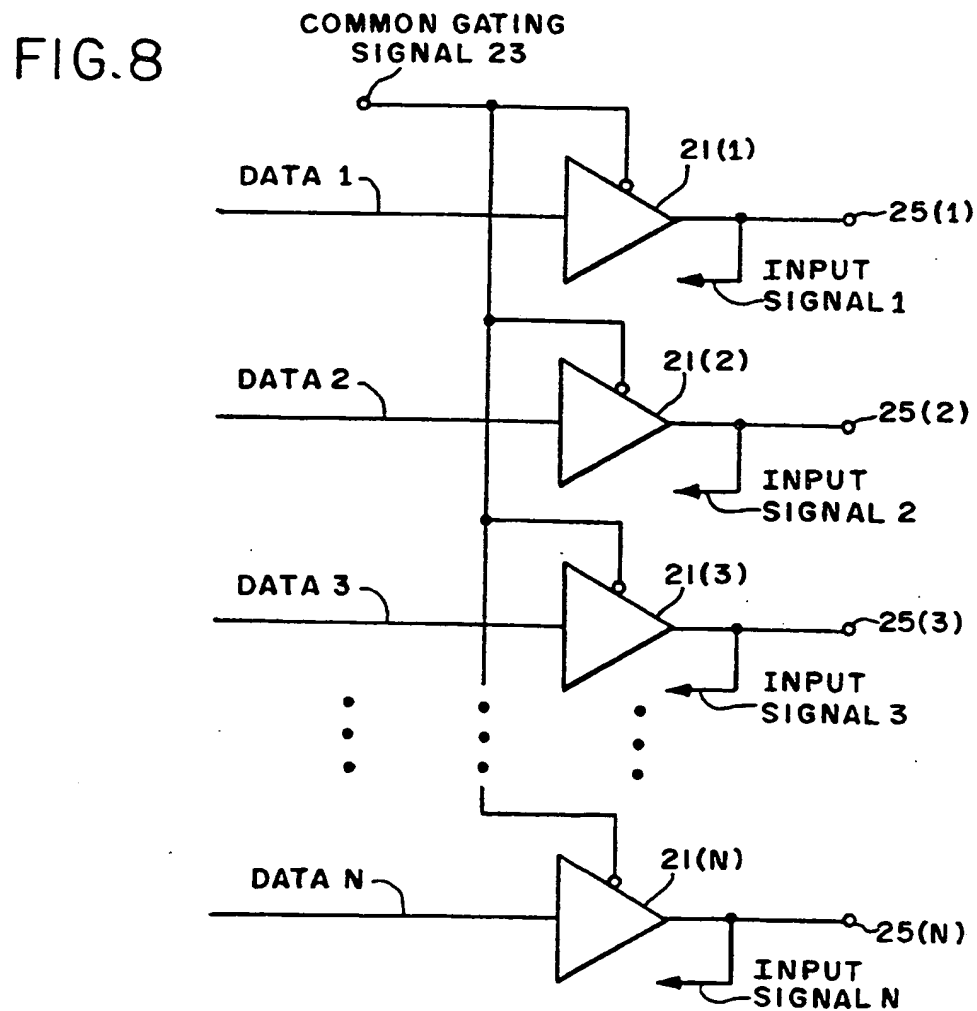
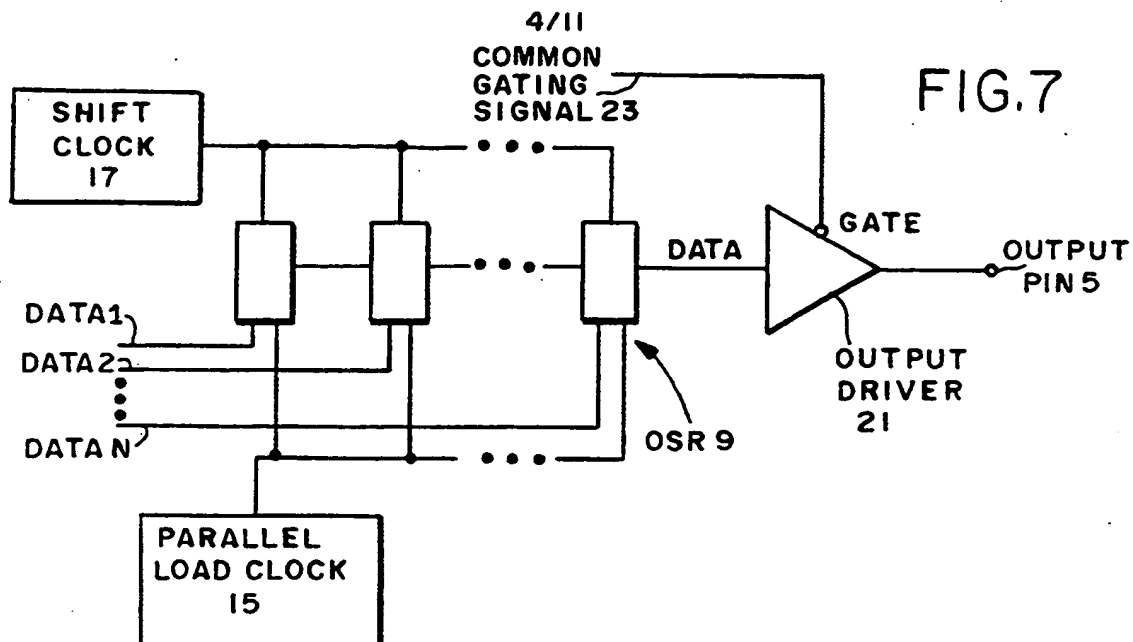
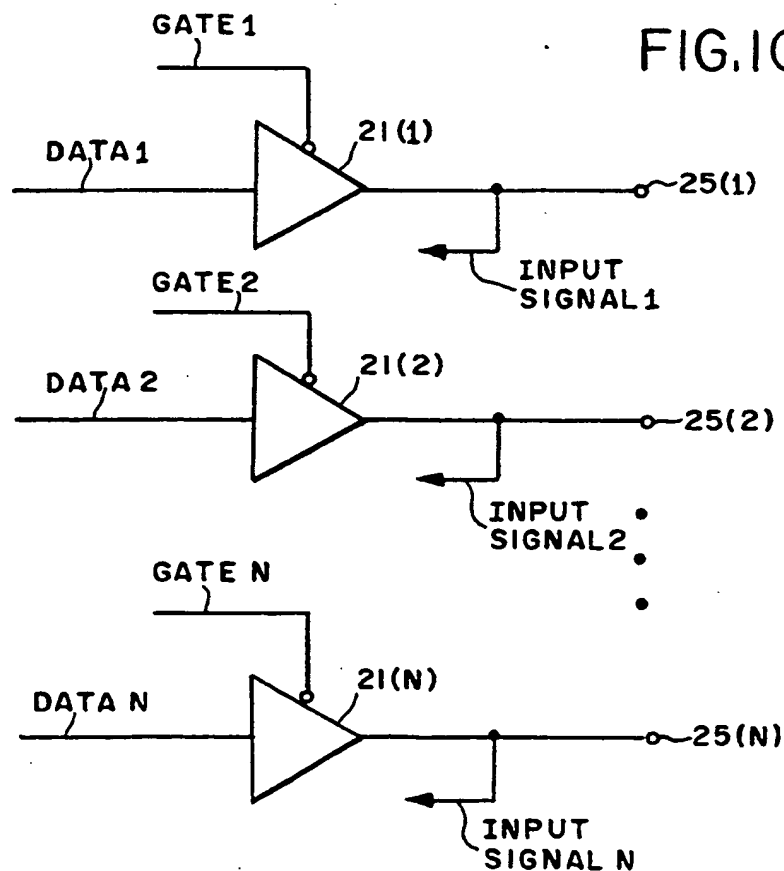
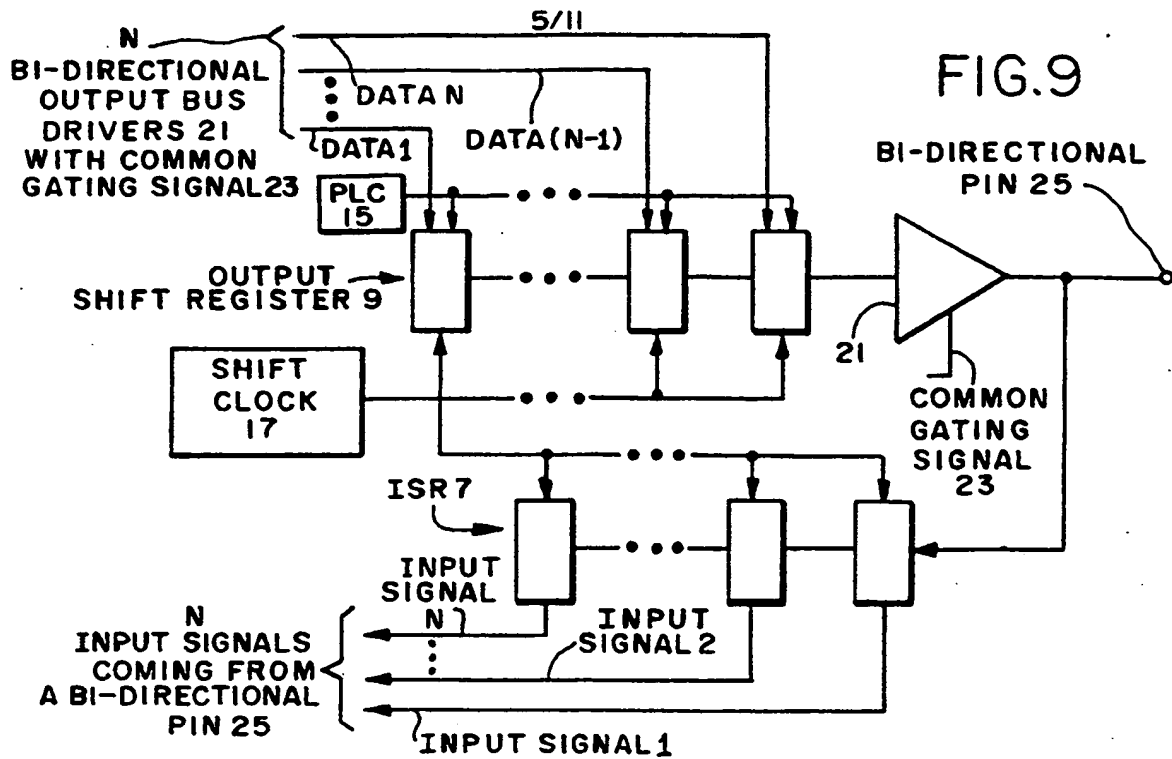


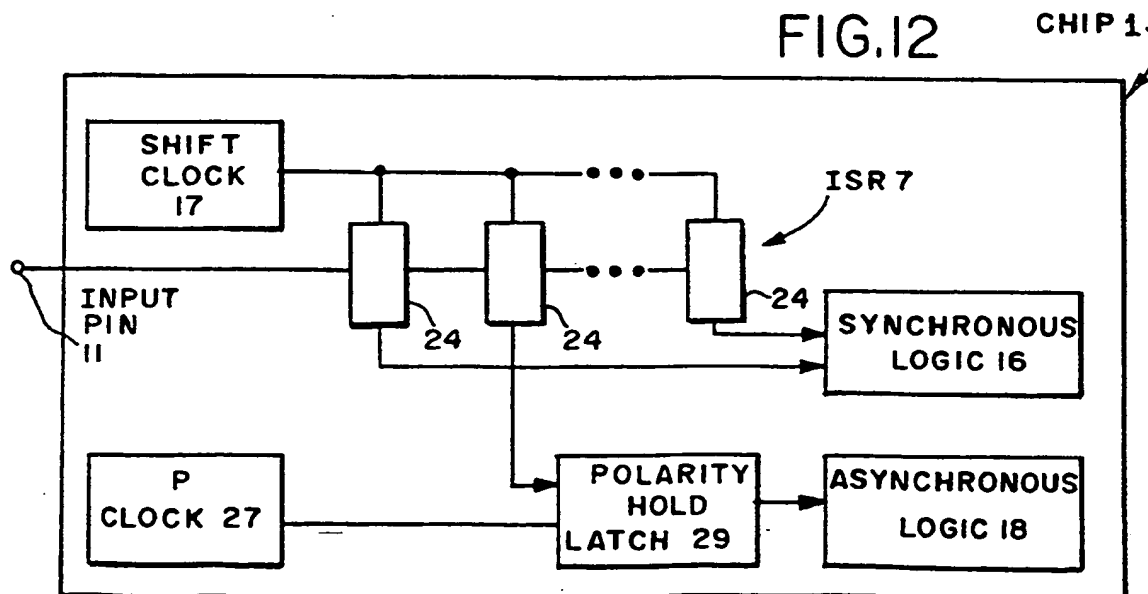
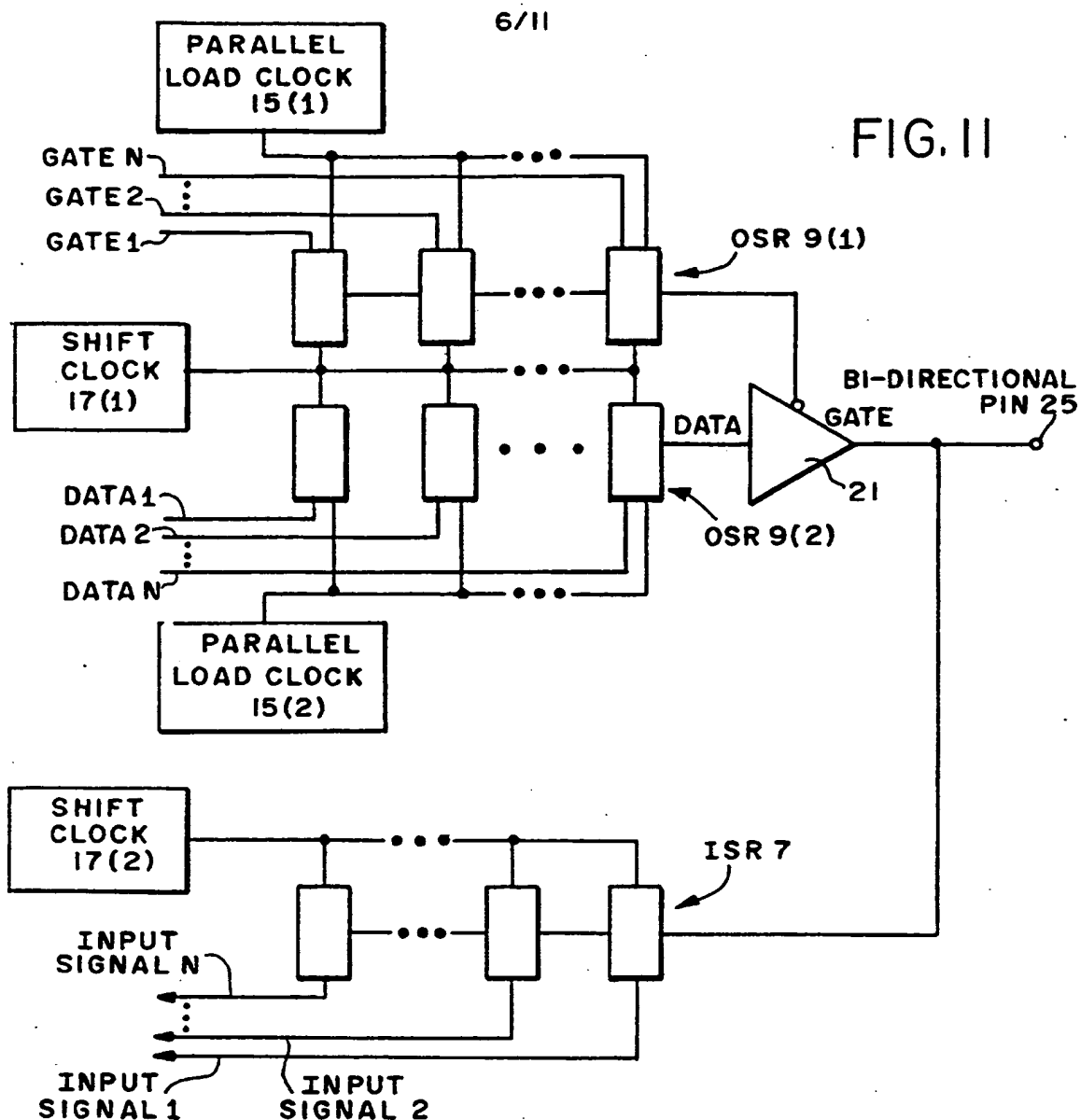
FIG. 6

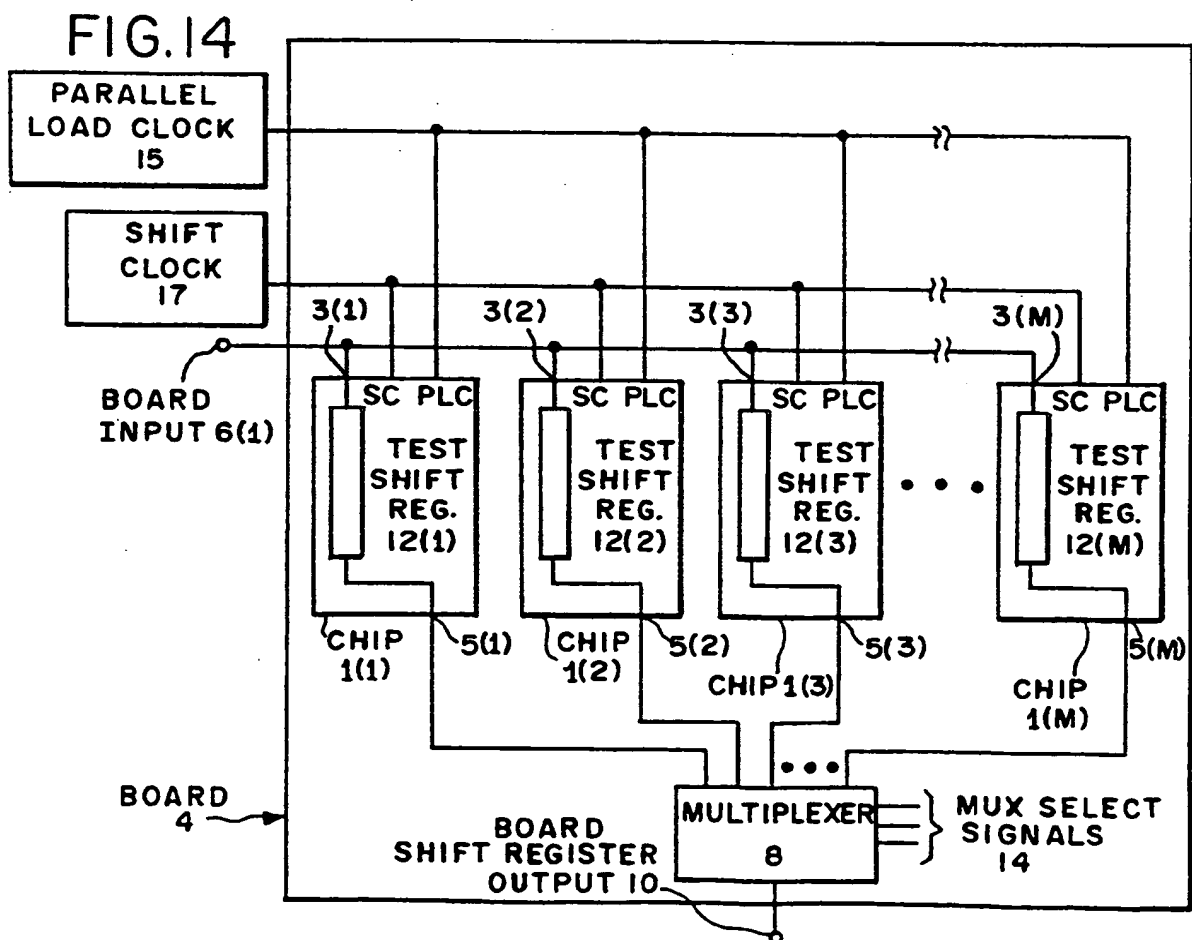
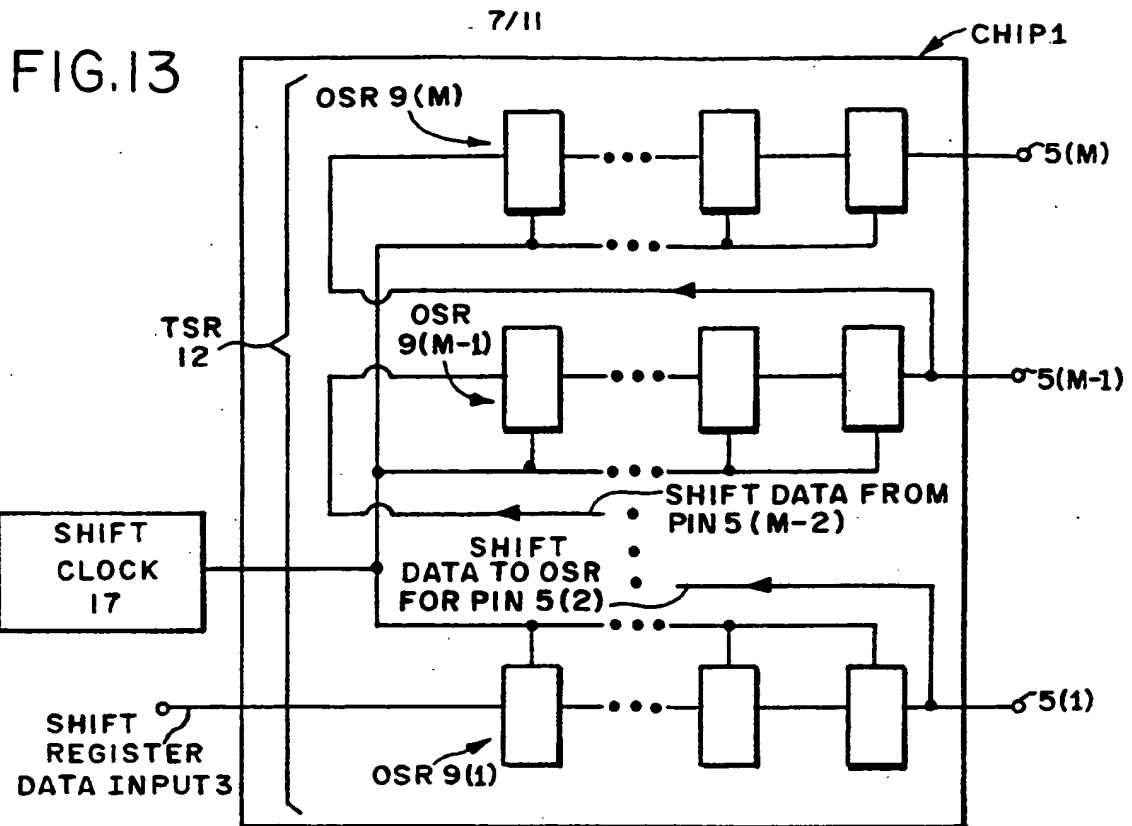












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FIG. 15

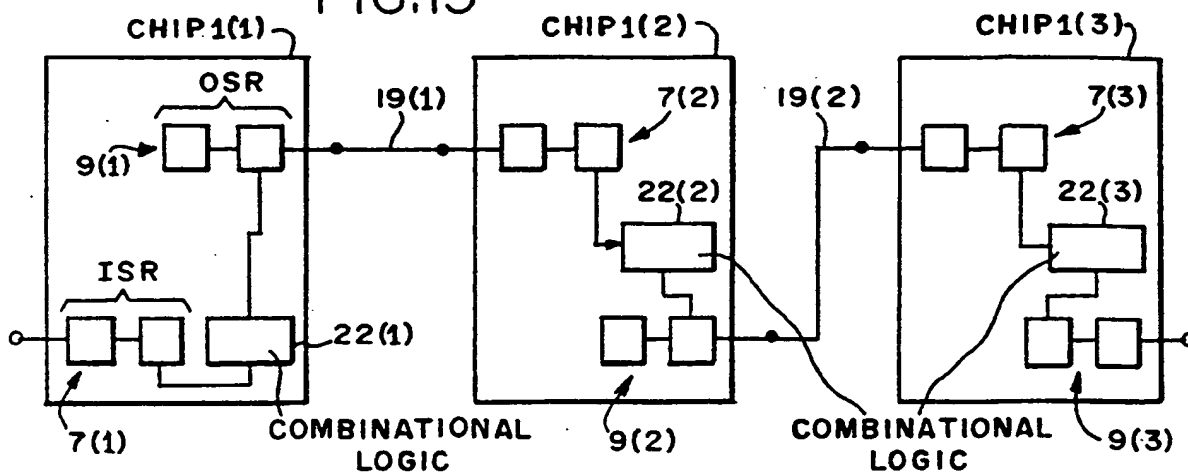


FIG. 16

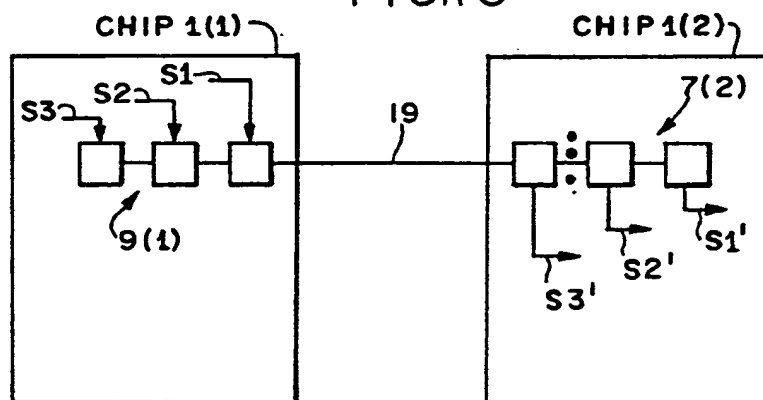
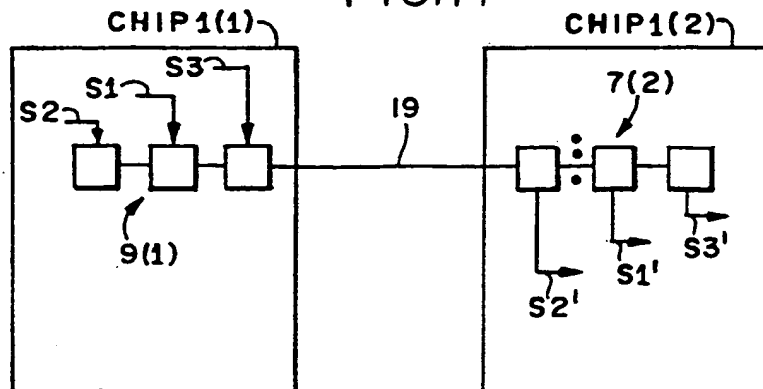
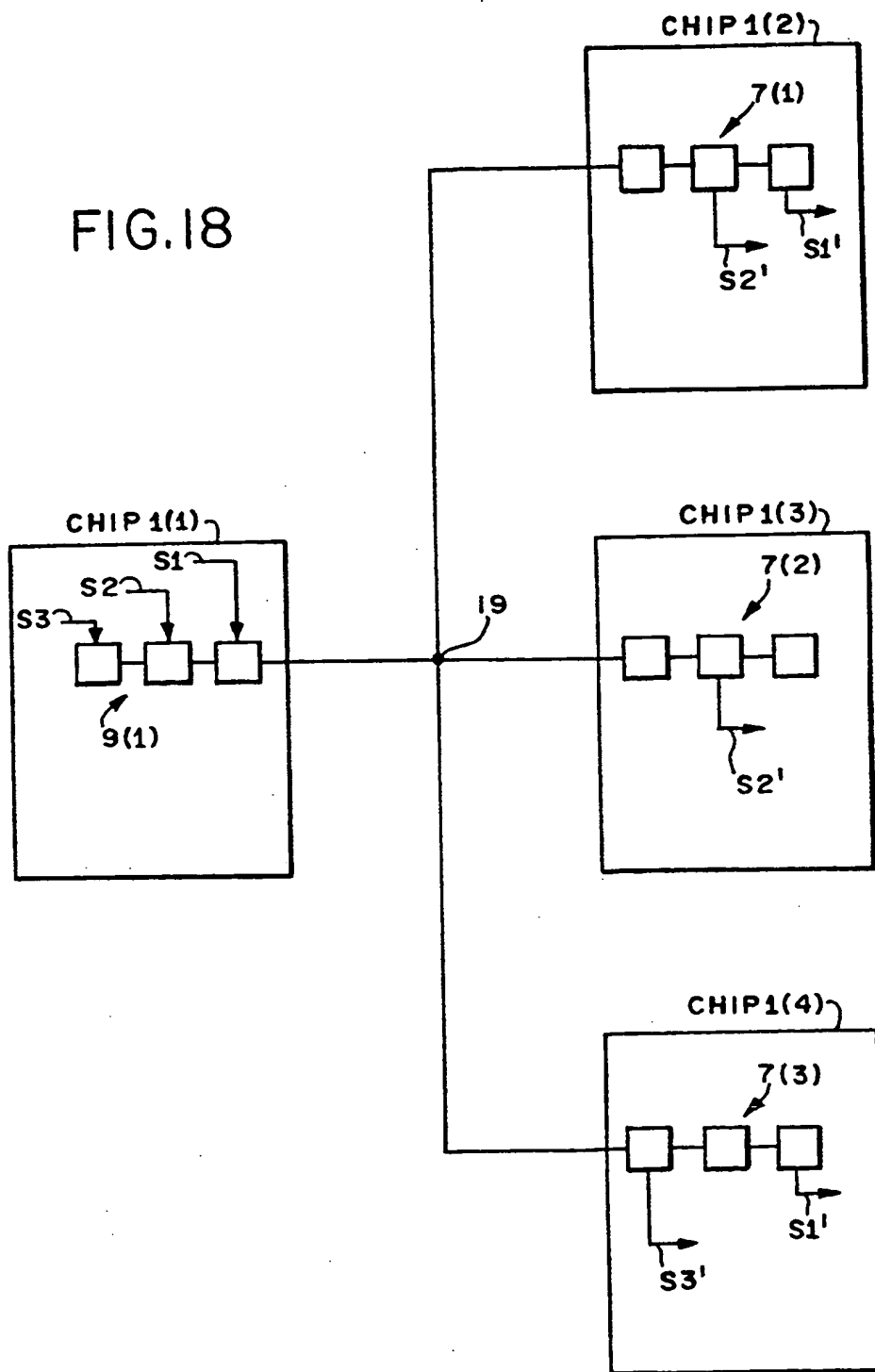


FIG. 17

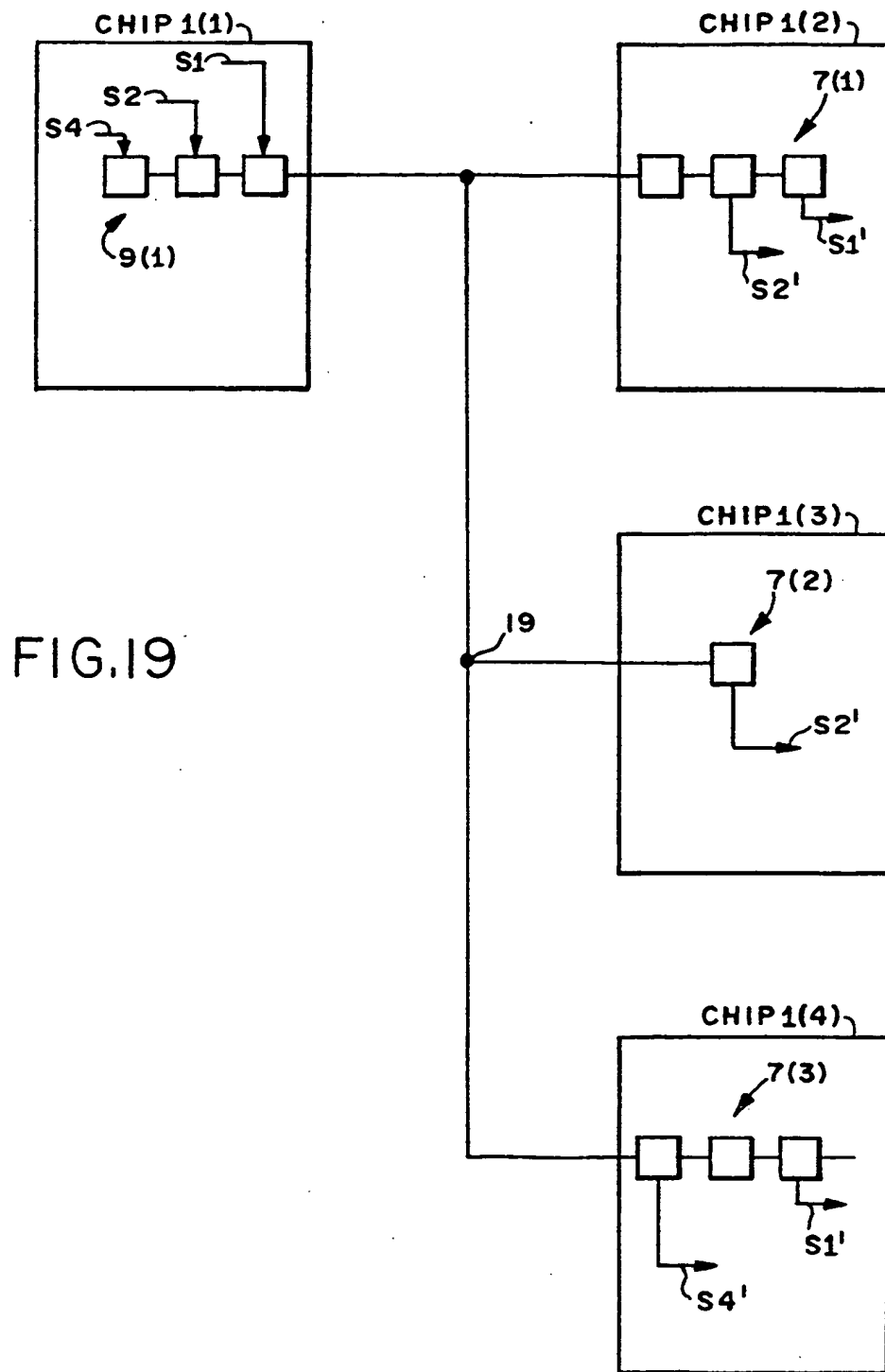


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FIG.18



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II/II

FIG.20

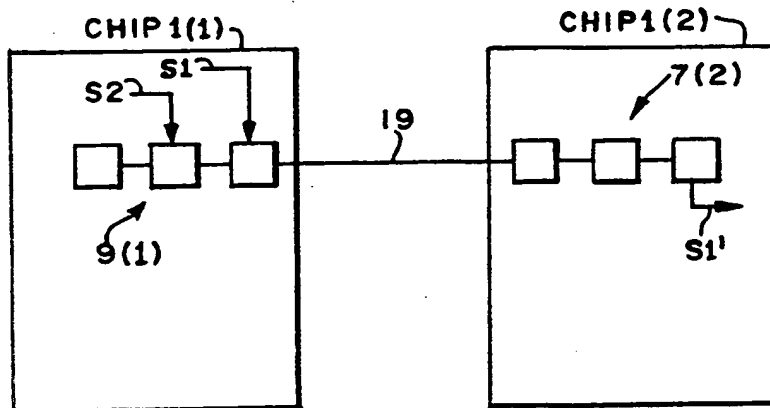


FIG.21

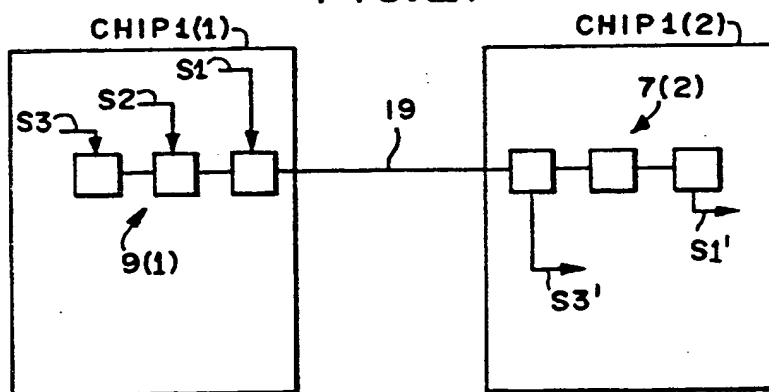
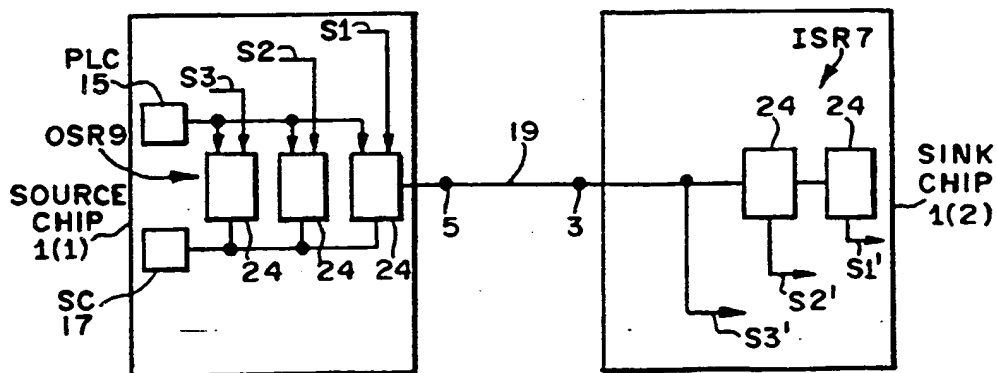


FIG.22





# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 92/07299

|   |   |   |
|---|---|---|
| <b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>   |   |   |
| According to International Patent Classification (IPC) or to both National Classification and IPC<br>Int.Cl. 5 H03K19/173;                      G06F1/22  |   |   |
| <b>II. FIELDS SEARCHED</b>  |   |   |
| Minimum Documentation Searched <sup>7</sup>   |   |   |
| Classification System   | Classification Symbols  |   |
| Int.Cl. 5   | H03K ;                      G06F  |   |
| Documentation Searched other than Minimum Documentation<br>to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>   |   |   |
|   |   |   |
| <b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>   |   |   |
| Category <sup>10</sup>  | Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>  | Relevant to Claim No. <sup>13</sup>                 |
| X   | MINI MICRO CONFERENCE RECORD May 1984, NEW YORK US<br>pages 1 - 6<br>STANLEY 'versatile serial protocol for a microcomputer-peripheral interface'                       | 1,2,7,<br>12,13,14                                  |
| Y   | see the whole document<br>---   | 3   |
| Y   | GB,A,2 164 769 (INTERNATIONAL STANDARD ELECTRIC CORPORATION)<br>26 March 1986   | 3   |
| A   | see the whole document<br>---   | 4   |
| A   | PATENT ABSTRACTS OF JAPAN<br>vol. 14, no. 238 (P-1050)21 May 1990<br>& JP,A,20 58 790 ( MITSUBISHI ELECTRIC CORP. ) 27 February 1990<br>see abstract<br>---<br><br>-/-- | 1,6,7   |
| <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>10</sup> Special categories of cited documents : <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p> </div> </div> |   |   |
| <b>IV. CERTIFICATION</b>  |   |   |
| Date of the Actual Completion of the International Search   |   | Date of Mailing of this International Search Report |
| 28 APRIL 1993   |   | 1 1. 05. 93   |
| International Searching Authority   |   | Signature of Authorized Officer                     |
| EUR PEAN PATENT OFFICE  |   | FEUER F.S.  |

| III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET) |   |                       |
|--|---|-----------------------|
| Category   | Citation of Document, with indication, where appropriate, of the relevant passages                | Relevant to Claim No. |
| A  | EP, A, 0 439 199 (ADVANCED MICRO DEVICES<br>INC.)<br>31 July 1991<br>see the whole document ----- | 1, 4                  |

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.**

US 9207299  
SA 64251

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
The members are as contained in the European Patent Office EDP file on  
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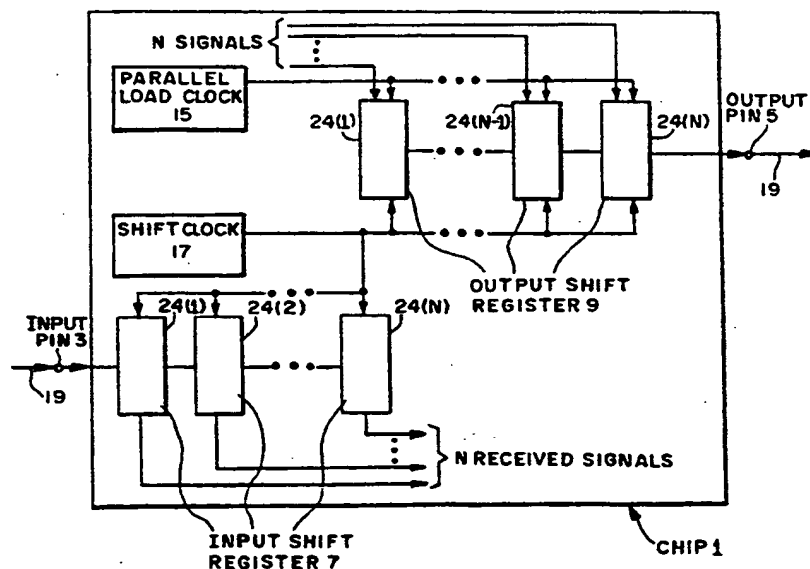
| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|---|---------------------|----------------------------|---------------------|
| GB-A-2164769                              | 26-03-86            | US-A- 4656620              | 07-04-87            |
| -----                                     |                     |                            |                     |
| EP-A-0439199                              | 31-07-91            | US-A- 4758747              | 19-07-88            |
|   |                     | EP-A- 0247809              | 02-12-87            |
|   |                     | EP-A- 0428504              | 22-05-91            |
|   |                     | JP-A- 63001215             | 06-01-88            |
|   |                     | US-A- 4939391              | 03-07-90            |
|   |                     | US-A- 5168177              | 01-12-92            |
| -----                                     |                     |                            |                     |



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

|  |           |  |
|--|-----------|--|
| <b>(51) International Patent Classification <sup>5</sup> :</b><br><b>H03K 19/173, G06F 1/22</b>  | <b>A1</b> | <b>(11) International Publication Number:</b> <b>WO 94/06210</b><br><b>(43) International Publication Date:</b> 17 March 1994 (17.03.94) |
| <b>(21) International Application Number:</b> PCT/US92/07299<br><b>(22) International Filing Date:</b> 28 August 1992 (28.08.92)<br><b>(71)(72) Applicant and Inventor:</b> GOEL, Prabhakar [US/US];<br>2050 Valparaiso Avenue, Menlo Park, CA 94025 (US).<br><b>(74) Agents:</b> RADLO, Edward, J. et al.; Fenwick & West, 2 Pa-<br>lo Alto Square, Suite 500, Palo Alto, CA 94306 (US).<br><b>(81) Designated States:</b> AT, AU, BB, BG, BR, CA, CH, CS,<br>DE, DK, ES, FI, GB, HU, JP, KP, KR, LK, LU, MG,<br>MN, MW, NL, NO, PL, RO, RU, SD, SE, US, European<br>patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT,<br>LU, MC, NL, SE), OAPI patent (BF, BJ, CF, CG, CI,<br>CM, GA, GN, ML, MR, SN, TD, TG). |           | <b>Published</b><br><i>With international search report.</i>   |

(54) Title: MULTICHIP IC DESIGN USING TDM



## (57) Abstract

In a multichip integrated circuit module (4), the number of effective input/output pins (3, 5, respectively) is increased by using techniques of TDM (time division multiplexing). A first chip (1) has at least one output shift register (9). A second chip (1) has at least one input shift register (7). Interconnection wires (19) couple the output shift registers (9) and the input shift registers (7). Means (15) are provided for loading data in parallel to the output shift registers (9). Means (17) are provided for sequentially shifting data through the output shift registers (9) over the interconnections (19) and into the shift input registers (7). Embodiments of the invention are described for use in conjunction with bi-directional pins (25), tri-state output drivers (21), and asynchronous logic (18).

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Description  
MULTICHIP IC DESIGN USING TDM

Field of the Invention

This invention pertains to the field of designing circuits having a plurality of integrated circuit (i.c.) chips, said design using techniques of TDM (time division multiplexing).

Description of Background Art

Dobbelaere et al., "Field Programmable MCM Systems -- Design of an Interconnection Frame", IEEE 1992 Custom Integrated Circuits Conference, pp. 4.6.1-4.6.4, addresses the same problem addressed by the present invention -- increasing the number of effective input/output pins in a multichip i.c. module -- by different techniques. The reference teaches programming a matrix at the corner of each chip to determine the interconnects among the inputs and outputs. The chips are FPGA's (field programmable gate arrays). The reference does not disclose the use of shift registers or TDM.

"Programmable Interconnect Architecture", Aptix Corporation Technology Backgrounder, Nov. 1991, pp. 1-14, and an Aptix press release dated January 1, 1992, describe use of an areal grid to preserve the ability to change the interconnects among a set of integrated circuit chips in applications where a logic is being implemented onto a set of multiple i.c.'s. These references do not disclose techniques of TDM. Shift registers are used, but only to determine which i.c.'s get connected to each other. The present invention uses shift registers to convey signal information from chip to chip.

U.S. patent 5,036,473 uses dedicated FPGA's solely to determine what active FPGA's get connected to which others. The reference discloses the use of software to drive and observe signals, but does not disclose the use of shift registers or TDM.

U.S. patent 5,109,353 discloses an array of programmable gate elements for emulating electronic

- 2 -

circuits and systems. It does not disclose the use of shift registers or TDM.

"Handbook of Hardware Modeling", Logic Modeling Systems Incorporated, February 1992, describes the use of software to drive and observe signals in a multichip module. Techniques disclosed in this reference can be used in conjunction with the invention described herein.

"Computer-Aided Prototyping", Quickturn Systems, Inc., 1991, pp. 1-4, discloses partitioning logic for a set of interconnected FPGA's and providing software stimulus to capture and observe the response. There is no disclosure of shift registers or TDM. This technology is further described in "FastForward", LSI Logic, September 1991, and "MARS Product Overview", PiE Design Systems, Inc. Similar technology is described in three press releases by InCA Integrated Circuit Applications: "InCA 'Virtual ASIC' Emulation System supports Xilinx 4000 family FPGAs", June 8, 1992; "Virtual ASIC, Automatic ASIC Emulation from InCA", 1991; and "Concept Silicon partitions your design onto multiple FPGAs".

#### Disclosure of Invention

The present invention is a multichip integrated circuit module (4) comprising at least two integrated circuit chips (1). The first chip (1) has at least one output shift register (9). The second chip (1) has at least one input shift register (7). Interconnections (19) couple the output register(s) (9) and the input shift register(s) (7). Means (15) are provided for loading data in parallel to the output shift register(s) (9). Means (17) are provided for sequentially shifting data through the output shift register(s) (9) over the interconnections (19) and into the input shift register(s) (7).

#### Brief Description of the Drawings

These and other more detailed and specific objects and features of the present invention are more fully disclosed in the following specification, reference being had to the accompanying drawings, in which:

- 3 -

Figure 1 is a sketch of an embodiment of the present invention in which an integrated circuit chip 1 uses at least one input shift register 7 and one output shift register 9.

5        Figure 2 is a sketch showing how the techniques of the present invention reduce the number of interconnection wires 19 among chips 1.

      Figure 3 is a sketch of an embodiment of the present invention in which the number of stages 24 in an input  
10       shift register 7 and output shift register 9 can be reduced by one.

      Figure 4 is a sketch of a chip 1 using tri-state output drivers 21.

      Figure 5 is a sketch of an embodiment of the present  
15       invention in which two output shift registers 9 are used in conjunction with a single output driver 21.

      Figure 6 is a sketch showing a plurality of tri-state output drivers 21, each having a common gating  
signal 23.

20       Figure 7 is a sketch showing how a single output shift register 9 can be used when the output drivers 21 have a common gating signal 23.

      Figure 8 is a sketch showing the use of bi-directional pins and a plurality of tri-state output  
25       drivers 21 having a common gating signal 23.

      Figure 9 is a sketch showing how a single bi-directional pin 25 can be used when a plurality of tri-state output drivers 21 have a common gating  
signal 23.

30       Figure 10 shows a chip 1 having a plurality of bi-directional pins 25, each coupled to an output driver 21 that has a different gating signal.

      Figure 11 shows a single pin 25 equivalent to the embodiment depicted in Figure 10.

35       Figure 12 shows an embodiment of the present invention in which asynchronous logic 18 is employed.

      Figure 13 shows an embodiment of the present invention in which a plurality of output shift registers 9 are daisy chained together.



- 4 -

Figure 14 shows an embodiment of the present invention in which a plurality of test shift registers 12 are multiplexed together.

5 Figure 15 shows an embodiment of the present invention in which the TDM sequence must be applied twice.

Figure 16 shows an embodiment of the present invention in which an interconnect 19 couples two chips 1.

Figure 17 shows how the interconnect 19 of Figure 16 can be reconfigured by reprogramming the first chip 1(1).

10 Figure 18 shows a single interconnect 19 coupling four chips 1.

Figure 19 shows how the interconnect 19 of Figure 18 can be reprogrammed by reprogramming the source chip 1(1).

15 Figure 20 shows an embodiment of the present invention in which an interconnect wire 19 couples two chips 1.

Figure 21 shows how the interconnect 19 of Figure 20 can be reprogrammed by adding a new signal S3 to the source chip 1(1).

20 Figure 22 shows an embodiment of the present invention in which the number of stages 24 in an input shift register 7 can be reduced by one.

#### Detailed Description of the Preferred Embodiments

25 A major purpose of this invention is to increase the effective number of input/output (I/O) pins 3,5 on integrated circuit chips 1 within a module 4 that comprises a plurality of said chips 1. The invention can be thought of as creating a number of virtual I/O pins 3,5 that is greater than the number of actual pins 3,5.

30 The invention also eases pressures on the system designer when the number of interconnect wires 19 on the module 4 is limited. Further, the invention enhances the reconfigurability of signal flow across chips 1.

35 An example where the invention is useful is in the design of a system 4 in which there is a need to fit a given amount of logic, which may be provided in the form of a netlist, into one or more of the chips 1. Normally, said chips 1 come with a fixed number of I/O pins 3,5 that are used for interconnections 19 among the chips 1.

- 5 -

The limited number of I/O pins 3,5 can greatly reduce the efficiency of utilizing the chips 1, and in some cases make the task of fitting the logic into the chips 1 extremely difficult.

5           The module 4 can be a production module, in which the chips 1 are executable and application-ready. Alternatively, module 4 can be a prototype module, in which the chips 1 are experimented with by the designer to create a system design. Changes in such a prototyping  
10           environment are typically done by a combination of hardware and software changes. Alternatively, module 4 can contain some production chips 1 and some programmable chips 1.

          Chips 1 are any chips for which the user has control  
15           over the contents, such as FPGA's (field programmable gate arrays), non-field-programmable gate arrays, custom i.c.'s, semi-custom i.c.'s (application specific integrated circuits), and standard cell i.c.'s. FPGA's are normally preferable, because of their flexibility.

20           The present invention makes use of techniques of TDM (time division multiplexing or time domain multiplexing). The execution of the system embodied in module 4 takes longer because of this, but in many applications this is of no concern. The TDM process is  
25           transparent to the operation of the logic embodied in module 4.

          Typically the TDM is implemented by shift registers 7,9, as illustrated in Figure 1. Each input pin 3 and each output pin 5 on a chip 1 is assigned a dedicated  
30           shift register, 7,9, respectively. The number of stages 24 in a shift register 7,9 is referred to as N. N is any positive integer greater than or equal to 2, and could be typically between 2 and 5. Preferably, N is the same for all shift registers 7,9 on a chip 1. If N were not the  
35           same, a separate shift clock 17 would be needed for each different value of N. In the chip 1 illustrated in Figure 1, the value of N is the same, and therefore there is but one shift clock 17.

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Each chip 1 can have a plurality of input pins 3 and a different number of output pins 5. The different chips 1 on a module 4 can have different numbers of input pins 3 and output pins 5.

5       The individual stages 24 of the shift registers 7,9 can be, for example, flip-flops, edge triggered latches, and pairs of polarity hold latches. When polarity hold latches are used, a pair of shift clocks 17 is required for use with the corresponding shift register 7,9.

10       The shift register 9 attached to an output pin 5 is referred to as an output shift register (OSR) 9, and functions as N virtual output pins 5. N internal signals from within the chip 1 can be loaded into the OSR 9 in parallel by means of activating a parallel load clock 15  
15 associated with the OSR 9. These signals are then serially shifted out of the OSR 9 over the corresponding output pin 5 using the shift clock 17 associated with said OSR 9. The signals travel over interconnection wires 19 to other chips 1 that need to receive the  
20 signals.

Similarly, the shift register 7 attached to an input pin 3 is referred to as an input shift register (ISR) 7, and functions as N virtual input pins 3. It can receive serially N signals from a board interconnect 19 through  
25 the associated input pin 3 by means of the shift clock 17 that is connected to said ISR 7. The received signals can then simultaneously be applied inside the chip 1 using their stored states within the stages of the ISR 7. No special clock is needed to unload the signals from  
30 the ISR 7, because once these signals are in the ISR 7, they are visible to the logic within the chip 1.

Preferably, a single parallel load clock 15 and a single shift clock 17 are used for all the ISR's 7 and OSR's 9 on the board 4.

35       Preferably, the OSR's 9, ISR's 7, and attendant parallel load and shift clocks 15, 17 are customized within peripheral regions of the gate arrays 1. Alternatively, the OSR's 9 and ISR's 7 are fabricated from logic normally present on the gate arrays 1.

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Figure 2 illustrates how the invention minimizes the number of interconnect wires 19 among chips 1,2 and minimizes the number of I/O pins 3,5 within a chip 1. Figure 2 illustrates the interconnections of OSR 9 within a source chip 1 and three ISR's 7 residing within three target (sink) chips 1. The target chips 1 could be identical or different in a hardware sense. A single interconnect wire 19 couples the chips 1. Three signals S1, S2, and S3 from the source chip 1 are conveyed to the three sink chips 1. If the TDM and shift register technique were not used, three interconnects 19 would be required. The interconnect wire 19 can be thought of as a TDM bus which bundles in the time domain the three signals S1, S2 and S3. Said TDM bus 19 is visible to all three sink chips 1.

As illustrated in Figure 2, not all of the three signals need to be used in each sink chip 1. (The signals within the sink chips 1 are primed for notational purposes.)

The TDM process described herein is transparent to the intended logic design. This transparency can be achieved in different ways, depending upon the degree of transparency needed. For example, if all chips 1 on the module 4 are synchronously clocked (which is preferable), the following two-step TDM process can be used, at a safe time after the application of each pulse from the system clock (not illustrated). The safe time is that amount of time needed for all of the signals in the logic to achieve a steady state, i.e., when the intended design has been programmed into the chips 1.

Step 1. The parallel load clock 15 (which is preferably a single clock applied to all output shift registers 9 on the board 4) is applied to effect a parallel capture of signals into all of the OSR's 9 on all the chips 1.

Step 2. Using the shift clock 17 (preferably a single clock used by all the ISR's 7 and OSR's 9 on all the chips 1), the contents of all of the OSR's 9 are shifted into the target ISR's 7 via the interconnects

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19. This shifting process involves N applications of shift clock 17 to all of the chips 1.

Exceptions to the above scheme exist for various reasons, such as: (1) Certain I/O pins are  
5 bi-directional pins 25 (see Figure 8). Such bi-directional pins 25 could be left unmodified. Signals involving such pins 25 are not affected by the above two steps. (2) Inputs 3 that receive direct clock signals (as opposed to data signals) do not require the use of an  
10 ISR 7. Such would be undesirable, because it would cause the clock to jiggle. Similarly, output pins 5 that carry clock signals going to other chips 1 do not require the use of OSR's 9. Clock signals cannot be transferred across chips 1 using TDM without significant impact to  
15 the intended logic. As such, it is not desirable to use such techniques for I/O pins 3,5 that carry clock signals.

Figure 12 shows that if the logic being prototyped is asynchronous, an additional latch 29 is needed for each ISR 7 stage 24 that drives a piece of asynchronous  
20 logic 18. Such a latch 29 is a voltage level or logic level sensitive latch that receives its data from an ISR 7 stage output and is clocked by yet another clock called the P clock 27. P clock 27 is shared among all chips 1 that have asynchronous logic. The function of this added  
25 latch 29 is to screen the shifting of the ISR 7 from the asynchronous logic 18. P clock 27 is pulsed once after the completion of the two usual TDM steps, described earlier, that are used to effectuate the transfer of signals across chip 1 boundaries using TDM. As shown in  
30 Figure 12, some of the stages 24 of the ISR 7 can drive synchronous logic 16, and others of the stages 24 can drive asynchronous logic 18.

As illustrated in Figures 13 and 14, multiple OSR's 9 can be connected into one daisy-chained composite "test  
35 shift register" (TSR) 12 on each chip 1 to facilitate the observation of the captured signals externally by shifting out the TSR 12. All of the observation can be performed at the output of pin 5(M). These observed signals can be used for debugging the prototype hardware,

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depending upon the availability of extra board 4 logic and pins 3,5. The contents of the TSR 12 can then be reloaded from the output 5(M) of the TSR 12 to the shift register data input 3 on the same chip 1 if it is desired to continue with the operation of the hardware. A preferred way of accomplishing this reloading is to make a connection on the chip 1 itself from output 5(M) to input 3, thereby creating a circular shift register.

The set of TSR's 12 can be multiplexed to be observable at the output 10 of the board 4 as illustrated in Figure 14. Multiplexer select signals 14 control the selection of the individual TSR 12 outputs by multiplexer 8. The input to all the TSR's 12 is injected via board input 6. The scheme depicted in Figure 14 is useful when there are more chip output pins 5 than the designer wants to observe than there are available board output pins 10.

Since the OSR's 9 are usable for debugging purposes, the designer can choose to provide extra, initially unused, stages 24 within some OSR's 9. These stages 24 are then available to be used for observing internal signals that the hardware designer may not have thought about earlier, for example, by changing the programming on the chip 1 to look at these stages 24.

It is possible to reconfigure the interconnects 19 among the chips 1 by sending a different set of signals on each interconnect 19 than was previously intended. When combined with the internal reconfigurability of the FPGA 1 itself, a powerful new type of reconfigurability is thereby created. Figure 14 shows a module 4 with a number of FPGA's 1 and set up for using TDM. To achieve a reprogrammable board 4, it is required that one must be able to reprogram both the logic on the chips 1 as well as the interconnects 19. The on-chip logic is already rather reprogrammable through the use of the FPGA's 1. To reprogram the interconnects 19, an FPGA 1 can be used as a programmable interconnect chip as in U.S. patent 5,036,473, cited above; or a programmable interconnect chip as described in the Aptix references cited above can be used. Alternatively, several programmable

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interconnect chips 1 may be used. A limited reprogrammability of interconnects is described in Figures 16-21.

5 Figure 16 shows three signals, S1, S2, S3, TDM'ed between chips 1(1) and 1(2). By reprogramming the first FPGA 1(1), the manner in which the three signals S1, S2, S3 connect can be changed, as shown in Figure 17. In effect, the connections 19 between the two chips 1 have been rewired.

10 Figure 18 shows four chips 1 with signals S1, S2, S3 connected as shown. By reprogramming the first chip 1(1), as shown in Figure 19, signal S3 crossing between chips 1(1) and chips 1(4) is changed to S4.

15 In Figure 20, two interconnected chips 1 are shown. Figure 21 shows how a signal can be added to the interconnect 19 just by reprogramming the individual chip 1(1) and not touching the interconnect 19.

20 The flexibility described herein results from chip 1 being able to reprogram a number of signals that are TDM'ed across to other chips 1. Traditional techniques limit the reprogrammability to a single signal.

25 Once the value N is fixed for a given system 4, the total number of signals that can be moved across the chip 1 boundaries is predetermined. The total number of signals movable is N multiplied by the number of unique interconnect wires 19 on the board 4. It is apparent that by increasing N, a capacity greater than what is initially needed for the total number of signals can be achieved. The additional capability is usable for greater flexibility in reconfiguring the interconnects 19.

30 Theoretically, it is possible to accomplish all interconnections between any two chips 1 by using two interconnect wires 19 between them: one to carry signals flowing in one direction, and the second to carry signals flowing in the opposition direction. In this extreme situation of maximum multiplexing, the shift registers 7,9 must have an N greater than or equal to the larger of the number of the input signals and the number of the

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output signals on any single chip 1. (One signal is associated with each stage 24 of a shift register 7,9.)

The techniques of the present invention can be selectively applied to areas of logic that are considered susceptible to change or require use of TDM to accommodate the number of signals that need to traverse across chip 1 boundaries. As such, ISR's 7 and OSR's 9 need not be placed on all qualifying I/O pins 3,5. Instead, if there are insufficient resources on the chip 1, the ISR's and OSR's 7,9 may be deployed only on enough I/O pins 3,5 to allow adequate signal flow through the chips 1. It should be noted that an interconnect 19 must have either ISR's 7 and OSR's 9 on all terminals of that interconnect 19, or else must have no ISR's 7 or OSR's 9 at all.

When the chips 1 are FPGA's, it is possible to make engineering changes to prototype hardware 4 by reprogramming the affected FPGA's 1 to (1) change the logic realized by certain FPGA's 1 and/or (2) modify the effective interconnects 19 by capturing different signals into one or more of the OSR's 9 and/or (3) change the signals that are made observable by capturing them into unused stages 24 of OSR's 9.

Figure 22 shows an optimized version of the scheme in Figure 2. Here, the contents of the OSR 9 can be made observable, while reducing the number of stages 24 in an ISR 7 by one. In this embodiment, the state of the last stage 24 of an OSR 9 is used as a substitute for the eliminated stage 24 of an ISR 7.

In certain prototyping situations, it may not be necessary to observe the contents of the OSR's 9. In these cases, the number of stages 24 needed in an ISR 7 and OSR 9 can be reduced by one, corresponding to the stage 24 the system designer does not need to observe. This reduction is achieved by using the scheme depicted in Figure 3. Figure 3 shows how N equals 2 can provide the capability to multiplex three signals across a single interconnect 19. In this embodiment, the final state of the interconnect 19 after application of the TDM sequence



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is used as one of the multiplexed signals for the sink chip 1(2). In contrast, the scheme depicted in Figure 2 does not have the sink chips 1 dependent upon the final state of the interconnect 19, but only on the states of the ISR's 7.

The scheme depicted in Figure 1 uses ISR's 7 and OSR's 9 to multiplex signals across chip 1 boundaries. Such a TDM sequence serves to transfer signals once across an interconnect 19. However, if there is a logic path that is not interrupted by a latch or other sequential logic (other than ISR's 7 and OSR's 9) and spans more than two FPGA chips 1, then the TDM sequence needs to be repeated. The total number of TDM sequence applications required is equal to the number of distinct board level interconnect wires 19 that are included in the logic path. Figure 15 shows a logic path of combinational logic 22 that spans two board level interconnect wires 19(1) and 19(2). There are no latches other than ISR's 7 and OSR's 9 in the path. As such, the TDM sequence needs to be applied twice to move the signal through the three chips 1. Notice that ISR's 7 and OSR's 9 force the use of TDM. Without ISR's 7 and OSR's 9, the signal from chip 1(1) to chip 1(2) to chip 1(3) would flow without any clocking.

The techniques of the present invention can be extended to bi-directional pins 25 and/or three state output drivers 21. (See Figure 4). Such a driver 21 typically has outputs of logical zero, logical one, and high impedance.

Buses 19 generally employ tri-state drivers 21 to allow multiple source chips 1 onto a single wire. Such buses 19 are intended by the designer to achieve efficient interconnects between a multitude of source chips 1 and some number of sink chips 1. Generally, one source chip output driver 21 is active while others are in a high impedance state, so that one source chip output driver 21 is driving all receivers in the bus 19. The architecture shown in Figure 1 cannot be employed directly in such a case. Figure 4 shows N output pins 5,

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with a tri-state driver 21 on each pin 5. The OSR 9 scheme of Figure 1 will not work here, because the high impedance state cannot be transmitted via an OSR 9 and an ISR 7. Instead, the scheme shown in Figure 5 needs to be employed. It should be noted that this scheme uses two OSR's 9 instead of one: the first OSR 9(1) to capture the N gating signals and the second OSR 9(2) to capture the N data signals. Output driver 21 sees the corresponding gate-data combination as the OSR's 9 are shifted out. Thus, output pin 5 sees the gated output from output driver 21. The generated TDM sequence of signals on output pin 5 combines with similarly generated TDM sequences from other output pins 5 that are connected with this first output pin 5.

Figure 6 shows N output pins 5 with high impedance drivers 21 that share a common output gating signal 23. Signal 23 either produces a high impedance on the outputs of drivers 21 or else transmits the input signals to the outputs. Figure 7 shows a corresponding single pin architecture that avoids the use of two OSR's 9 but still places output driver 21 between the single OSR 9 and the output pin 5. The use of two OSR's 9 is avoided because of the presence of the common gating signal 23.

Figure 8 shows a typical N bi-directional pin 25 configuration with a common output gating signal 23. In Figure 8, the same pin 25 is used to both output a signal from the chip 1 as well as to receive signals from the outside. To achieve a single pin 25 architecture for TDM of the N signals, the scheme of Figure 9 is employed. In Figure 9, the architecture of Figure 7 is used to feed the outputs of the N drivers 21, and a single ISR 7 is used for the N input signals as in the Figure 1 embodiment.

Figure 10 shows N bi-directional pins 25, each with a different gating output signal. The single-pin 25 architecture equivalent for TDM of the N signals uses the scheme shown in Figure 11. In Figure 11, the architecture of Figure 5 is employed for the N output

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drivers 21, and a single ISR 7 is applied to the N input signals as in the Figure 1 embodiment.

Personalization instructions are injected into module 4, e.g., by techniques described in U.S. patent  
5 5,109,353 cited above. More than one logic design can be introduced into the module 4 by different personalization instructions. Software that is intended to provide automatic or interactive partitioning of the intended system design, such as Concept Silicon from InCA cited  
10 above, can exploit the knowledge of the existence of ISR's 7 and OSR's 9 to help pack more logic into each of the programmable chips 1 and/or to minimize the number of interconnection wires 19.

The software is executed on a computer external to  
15 module 4, e.g., a workstation. The software can be standalone (not physically coupled to module 4) software that exploits the hardware architecture of the module 4 as introduced by the invention. Alternatively, there can be physical coupling between the software and the module  
20 4, e.g., the computer on which the software is executed can have an electrical connection to the module 4, over which the personalization created by the software is downloaded into the module 4.

The benefit of minimizing the number of chips 1 is  
25 obvious. The benefit of minimizing the number of interconnects 19 is significant. If the prototype board 4 is intended to utilize Aptix-type programmable interconnect chips, minimizing the number of interconnects 19 will reduce the number of Aptix  
30 components needed to achieve programmable interconnects. Either the software is told the number of virtual I/O's 3,5 rather than the actual number; or else the software is told all about the ISR's 7 and OSR's 9 so that it will take this information into account when it does the  
35 partitioning. The programmable interconnect chip does not always need to be changed. Rather, ISR's 7 and/or OSR's 9 are placed on the chips 1 to which the programmable interconnect chip is connected, thereby enhancing the programmable interconnect chip.

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Combining the use of the present invention with the use of one or more programmable interconnect chips can allow the board 4 designer the flexibility of creating additional interconnects 19 among chips 1. Programmable  
5 interconnect chips are used to interconnect among two or more I/O pins 3,5. These I/O pins 3,5 could also have ISR's 7 and OSR's 9 on board the chip 1, thus providing a greatly increased number of programmable interconnects.

The configuration of the prototype board 4 is  
10 changed by a combination of hardware and software. For hardware changes, interconnects 19 are reprogrammed, FPGA's and/or programmable interconnect chips 1 are reprogrammed, FPGA's 1 are added or subtracted, and connections are obliterated using lasers. For software  
15 changes, software other than the partitioning software is used to, e.g., reprogram the Aptix chip(s) 1.

The above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. The scope of the  
20 invention is to limited only by the following claims. From the above discussion, many variations will be apparent to one skilled in the art that would yet be encompassed by the spirit and scope of the invention.

What is claimed is:

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Claims

1. A multichip i.c. module comprising:  
at least two integrated circuit chips, a first  
chip having at least one output shift register and a  
5 second chip having at least one input shift register;  
interconnections coupling the output shift  
register(s) and the input shift register(s);  
means for loading signals in parallel to the  
output shift register(s); and  
10 means for sequentially shifting signals through  
the output shift register(s) over the interconnections  
and into the input shift register(s).
2. The multichip i.c. module of claim 1 wherein  
all chips are clocked synchronously.
- 15 3. The multichip i.c. module of claim 1 wherein at  
least one chip contains asynchronous logic, said chip  
comprising an input shift register that is coupled to  
said asynchronous logic via a polarity hold latch;  
wherein:  
20 said polarity hold latch is clocked by a P  
clock.
4. The multichip i.c. module of claim 1 wherein at  
least some of the chips are gate arrays from the set  
comprising FPGA's and non-field-programmable gate arrays.
- 25 5. The multichip i.c. module of claim 4 wherein  
the output shift register(s), the input shift  
register(s), and associated clocking are customized  
within peripheral regions of the gate arrays.
6. The multichip i.c. module of claim 4 wherein  
30 the output shift register(s) and input shift register(s)  
are fabricated from logic normally present on the gate  
arrays.
7. The multichip i.c. module of claim 1 wherein  
the means for loading signals is a parallel load clock.
- 35 8. The multichip i.c. module of claim 1 wherein  
the module is a production module containing executable  
chips.

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9. The multichip i.c. module of claim 1 wherein the multichip module is a prototype module containing at least some experimental chips.

5 10. The multichip i.c. module of claim 1 further comprising software means to partition logic among the chips, said software means exploiting information concerning the particular architecture of the module.

11. The multichip i.c. module of claim 1 wherein said module contains a programmable interconnect chip.

10 12. In a multichip i.c. module comprising at least two integrated circuit chips, each chip having a plurality of I/O pins, said module having inter-i.c. connection wires interconnecting said pins, a method for increasing the effective number of I/O pins, said method  
15 comprising the steps of:

time division multiplexing signals at an output pin of a first chip; and

sending said signals over a connection wire to an input pin of a second chip.

20 13. The method of claim 12 wherein all chips are clocked synchronously.

14. The method of claim 12 wherein said step of time division multiplexing comprises the substeps of:

25 parallel loading signals into an output shift register within a first chip; and

accessing signals in parallel from an input shift register within a second chip.

30 15. The method of claim 14 wherein at least some of the chips are gate arrays from the set comprising FPGA's and non-field-programmable gate arrays.

16. The method of claim 15 wherein the output shift register(s) and input shift register(s) are customized within peripheral regions of said gate arrays.

35 17. The method of claim 15 wherein the output shift register(s) and input shift register(s) are fabricated from logic normally present on said gate arrays.

18. The method of claim 14 wherein the input and output shift registers comprise stages fabricated from

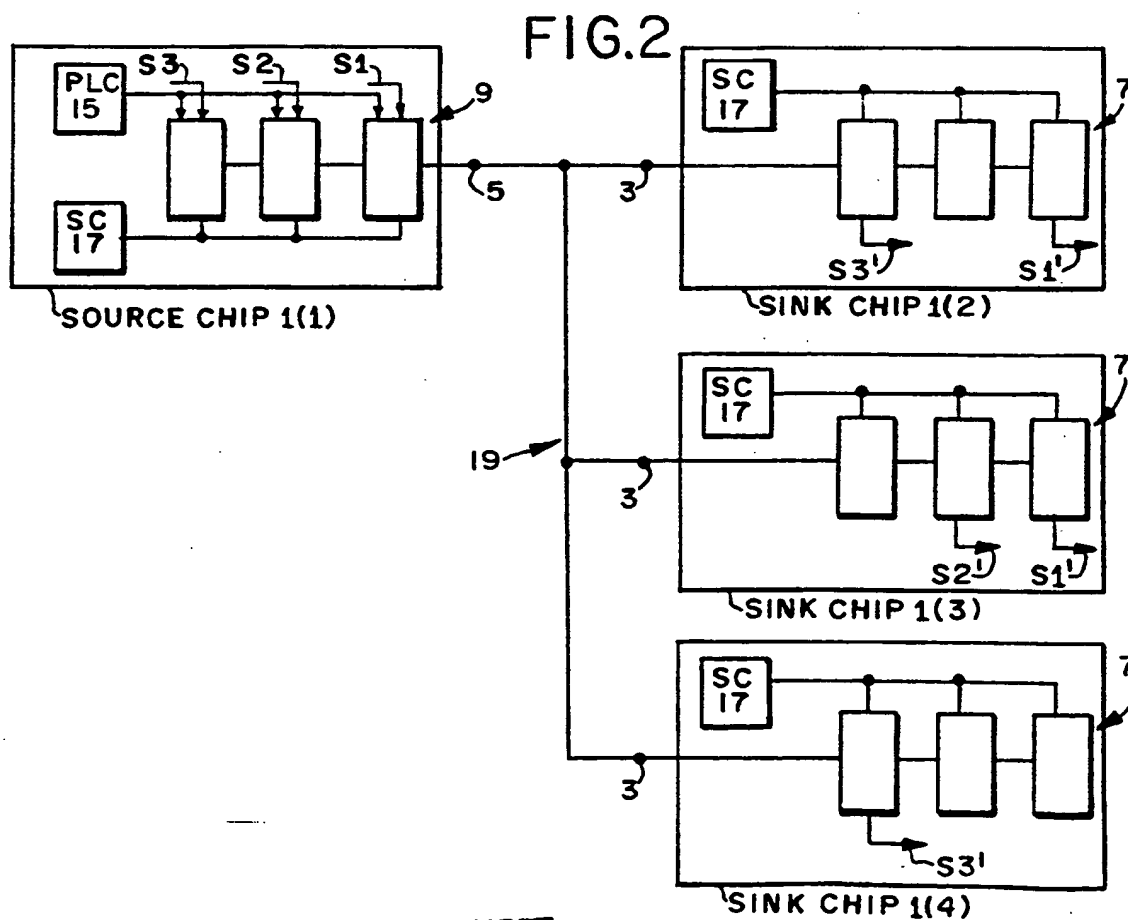
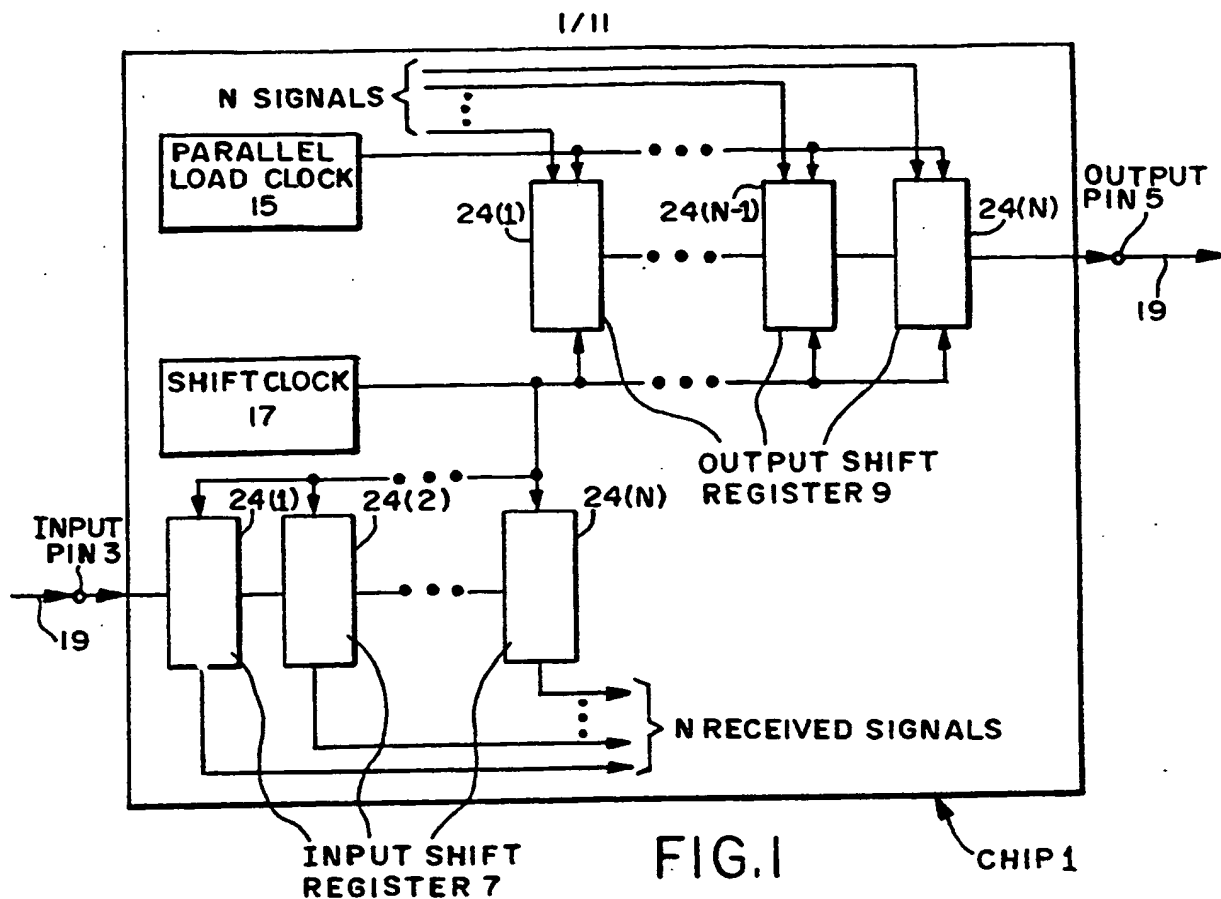
- 18 -

items from the group of items comprising flip-flops, edge triggered latches, and pairs of polarity hold latches.

19. The method of claim 18 wherein one of said stages is reserved for debugging purposes.

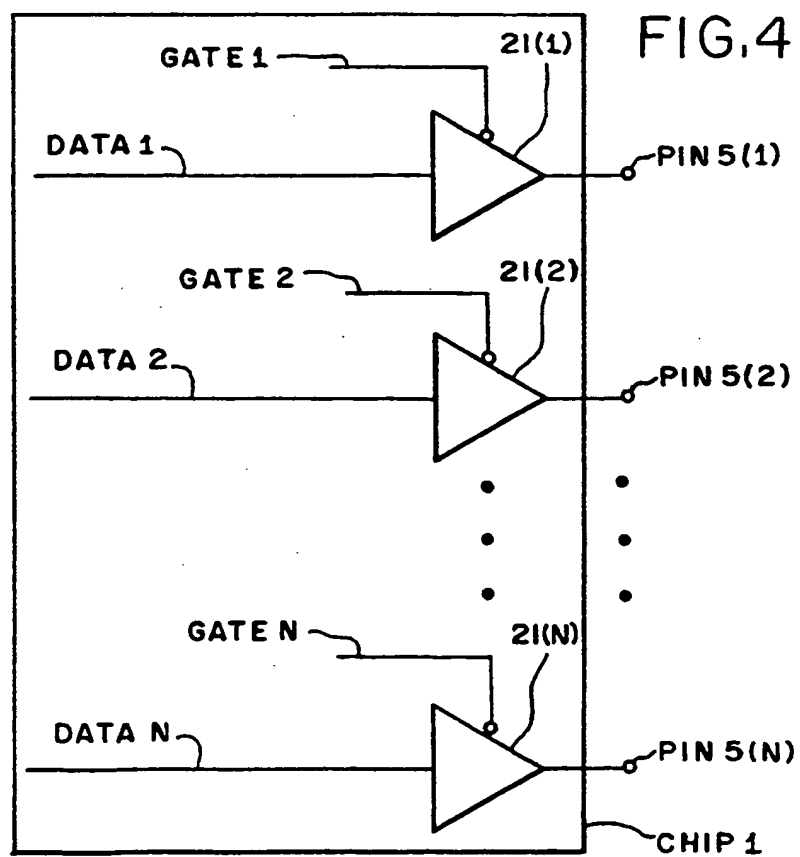
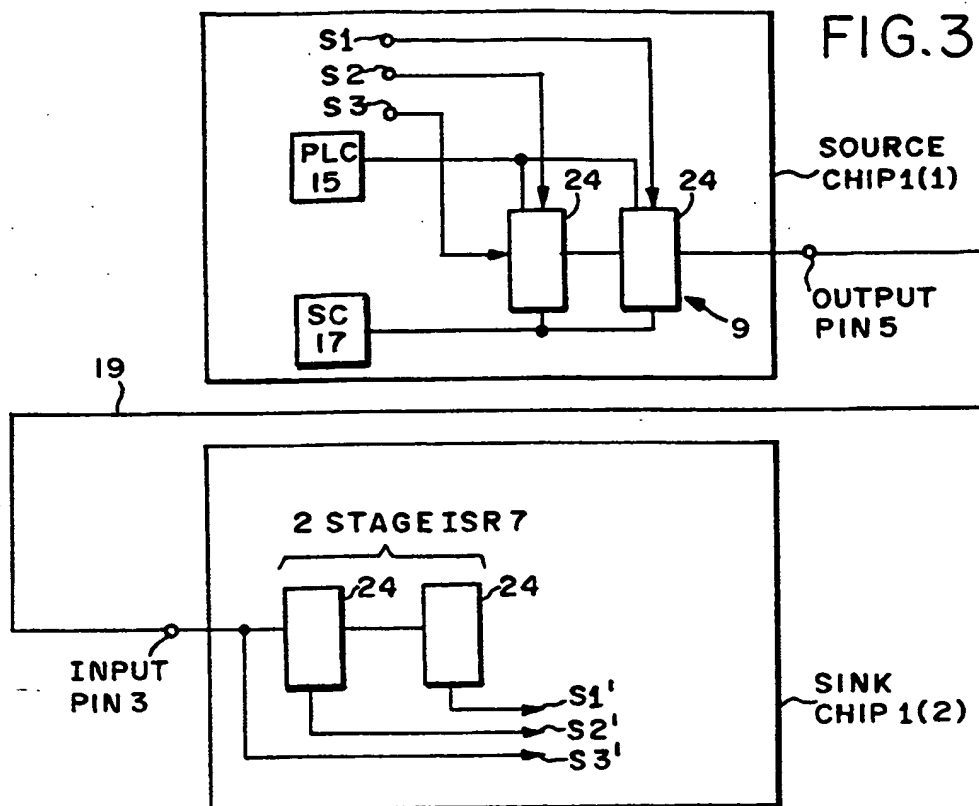
5       20. The method of claim 12 further comprising the additional step of determining a logic design for the module by use of partitioning software that exploits information concerning the particular architecture of the module.

10       21. The method of claim 12 further comprising the step of observing said signals at said output pin for test purposes.





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FIG.5

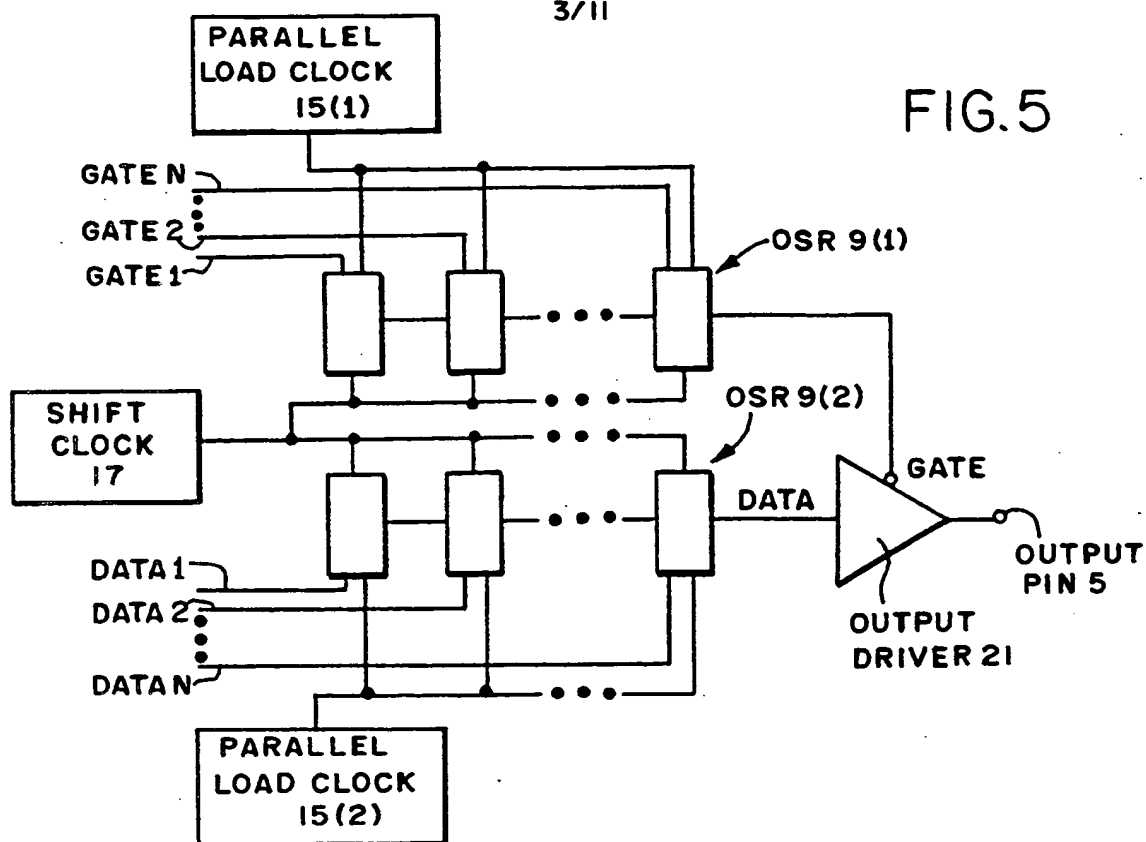
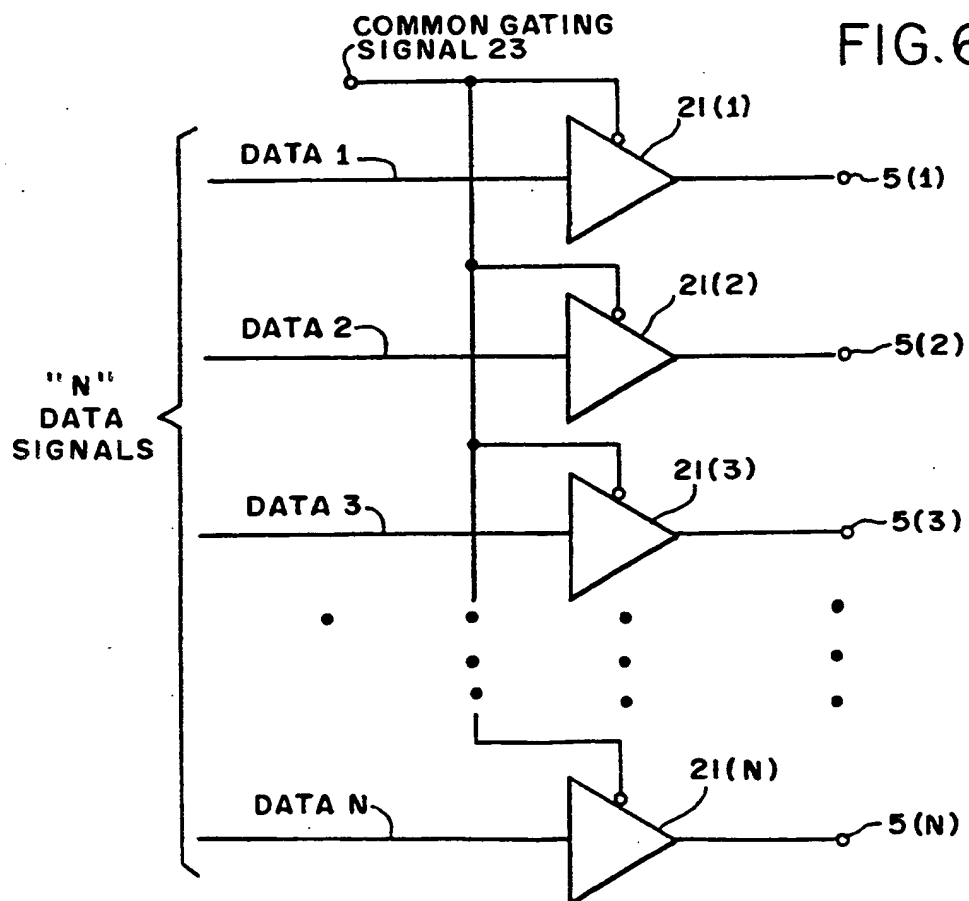


FIG.6



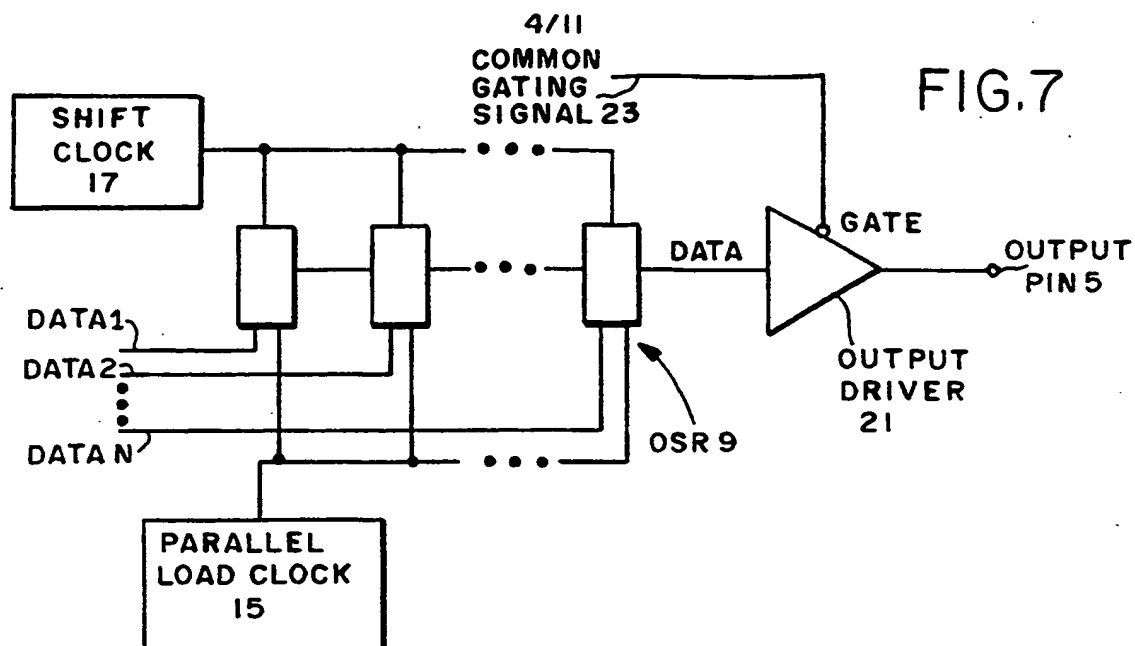
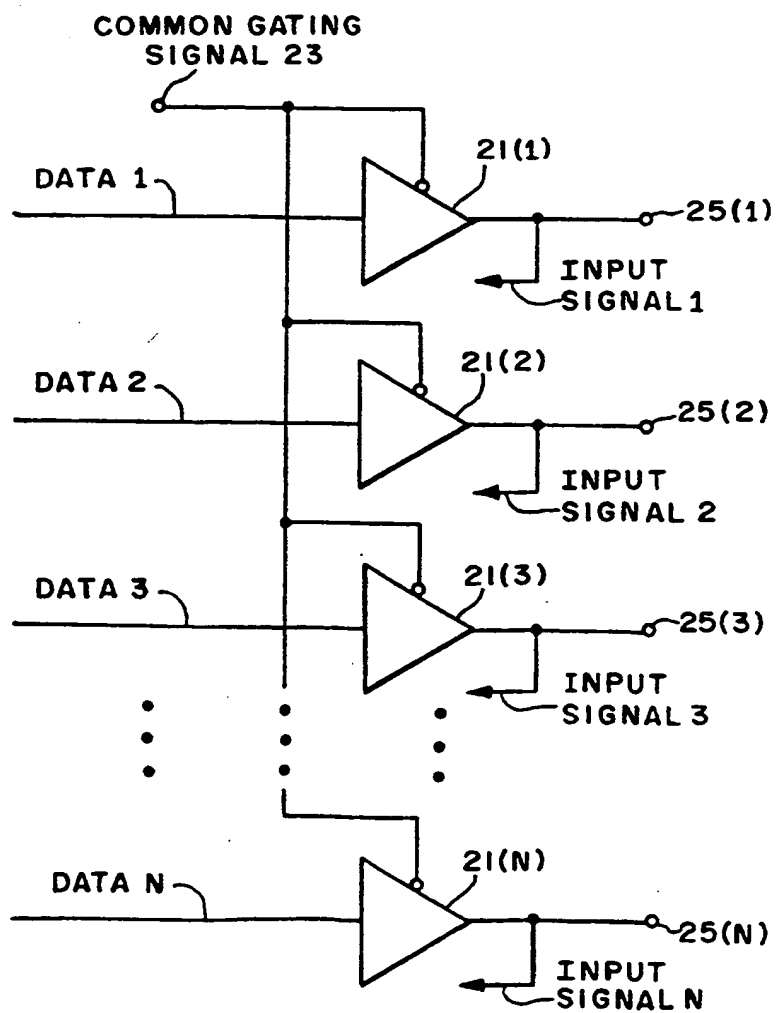
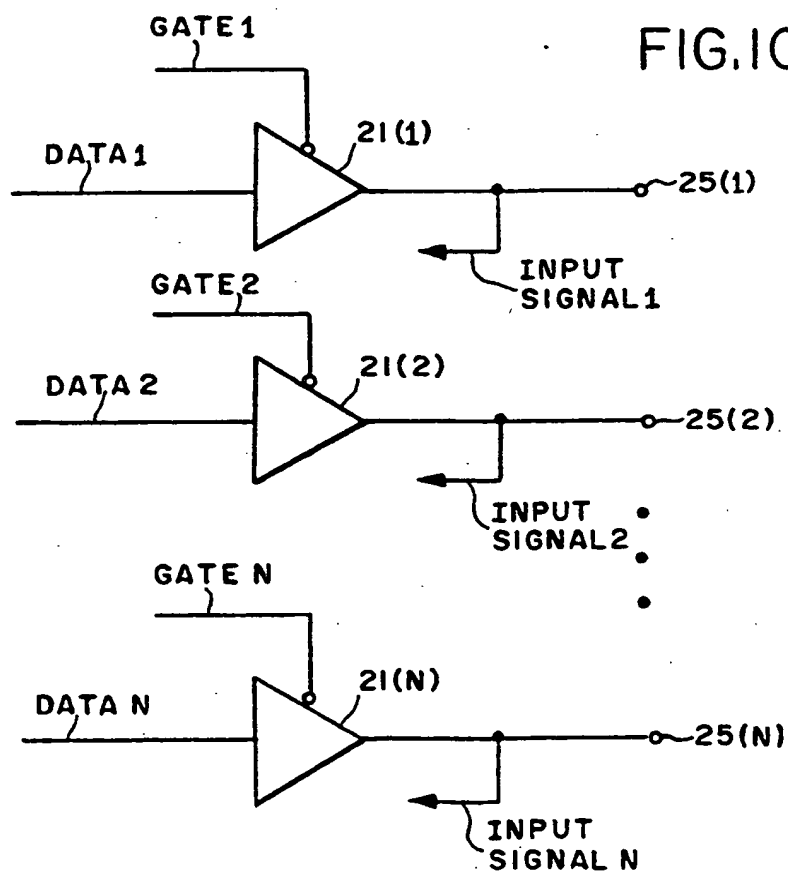
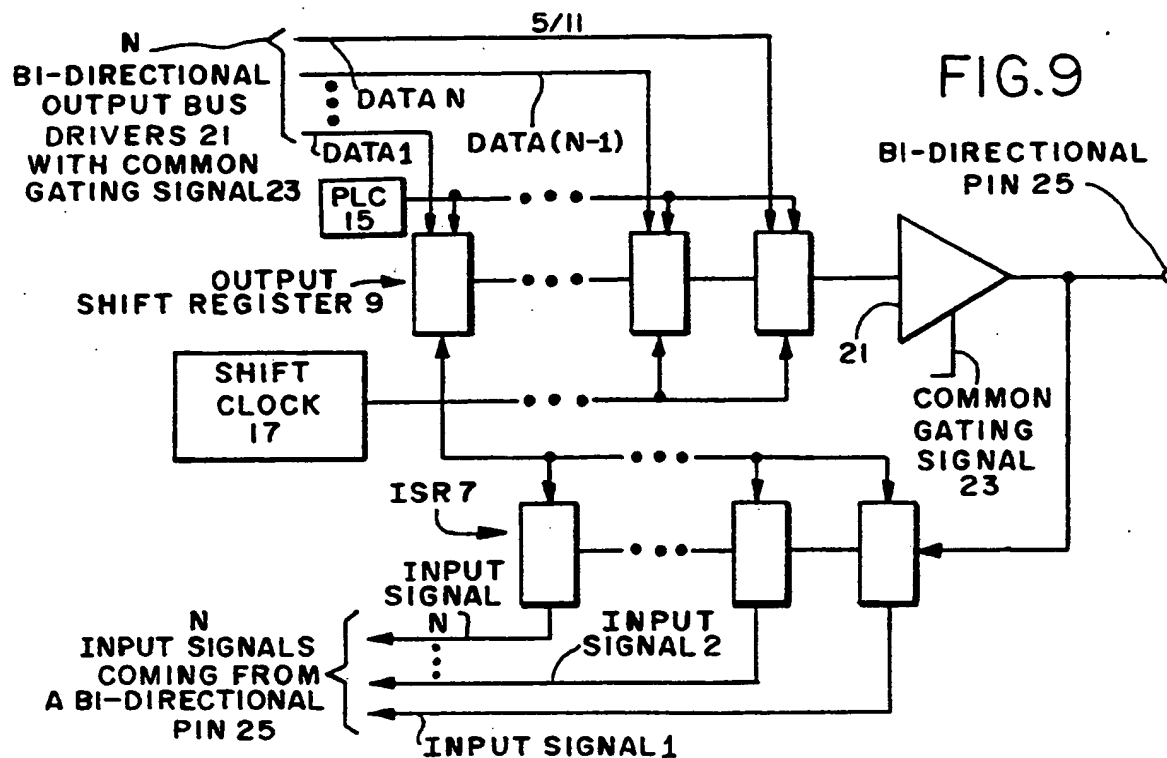


FIG. 8





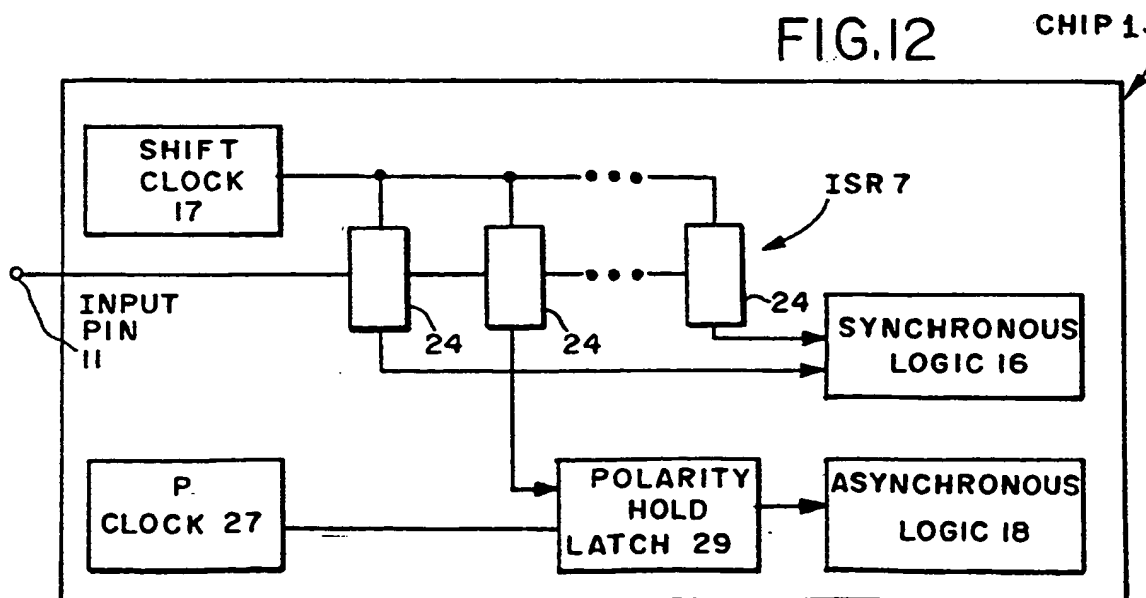
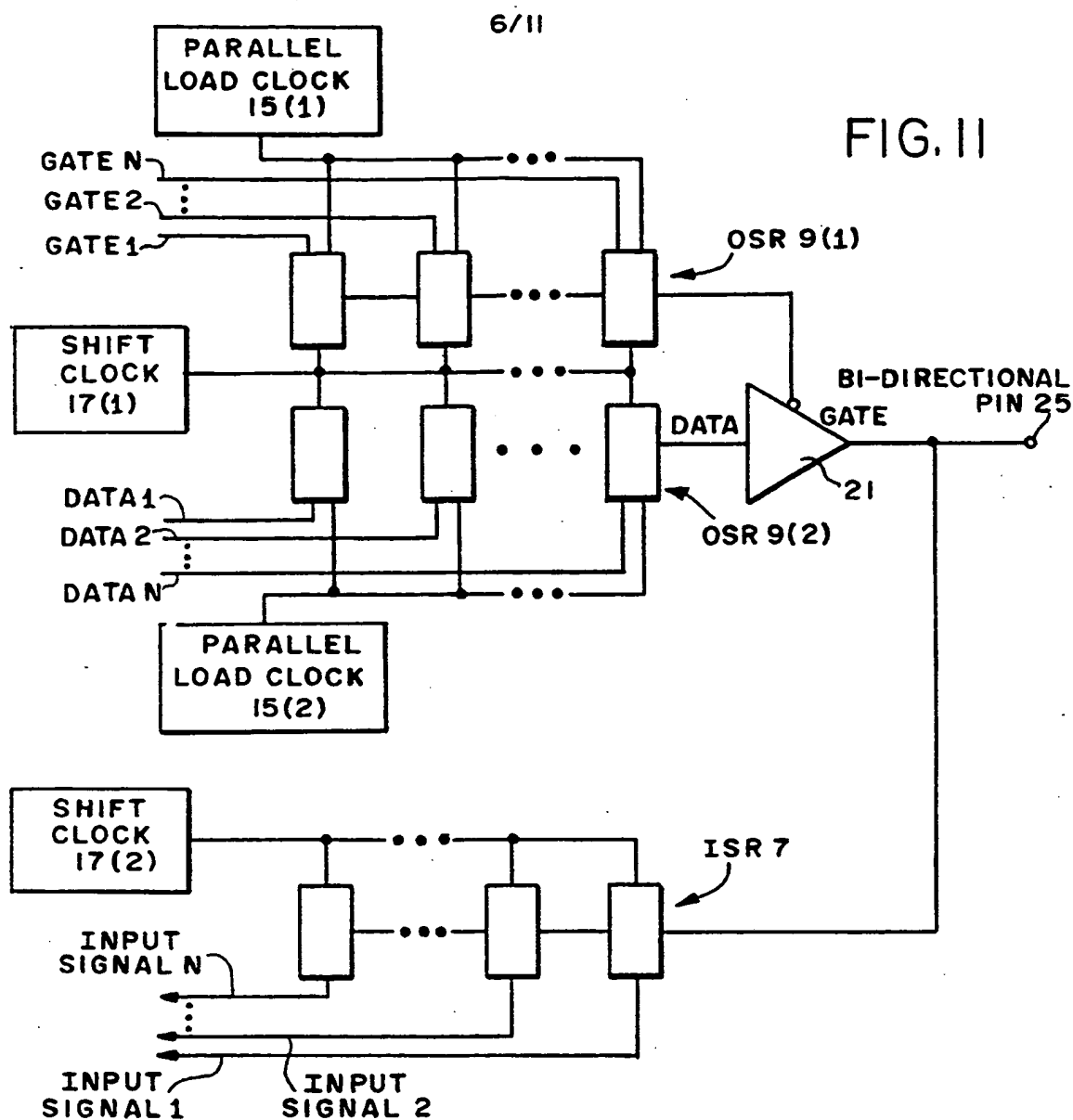


FIG.13

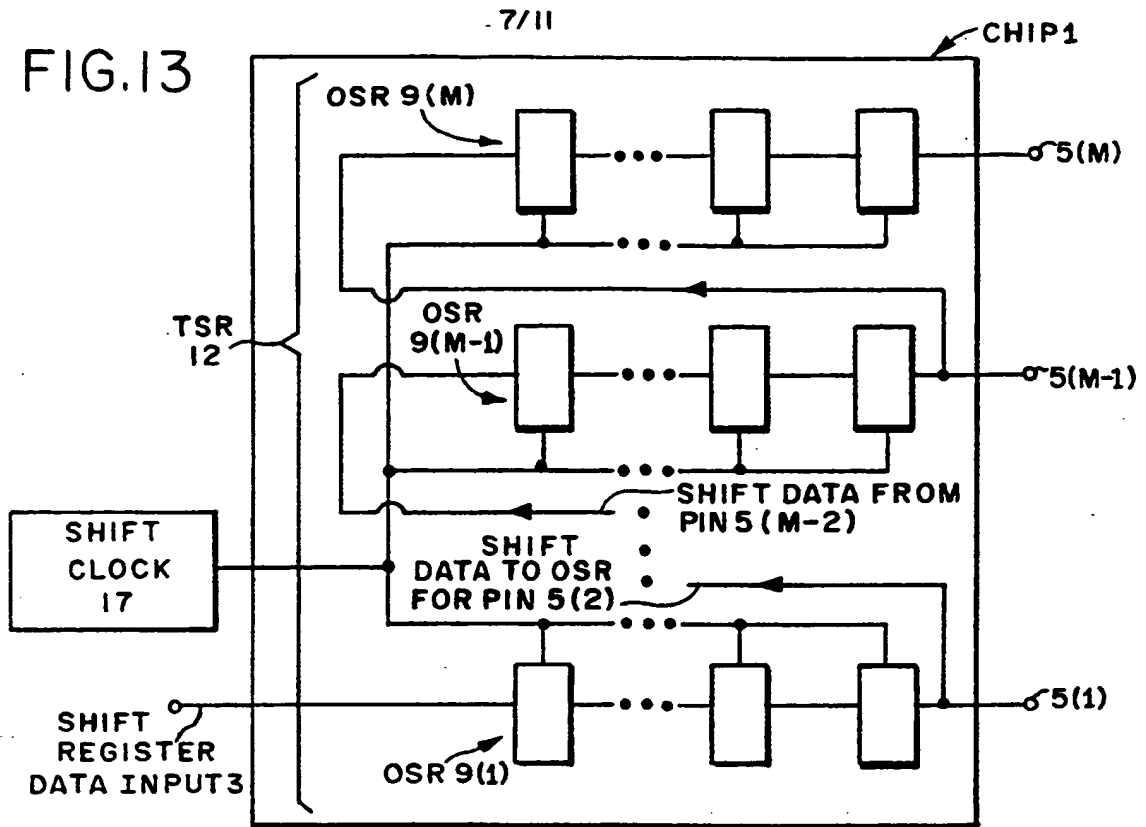
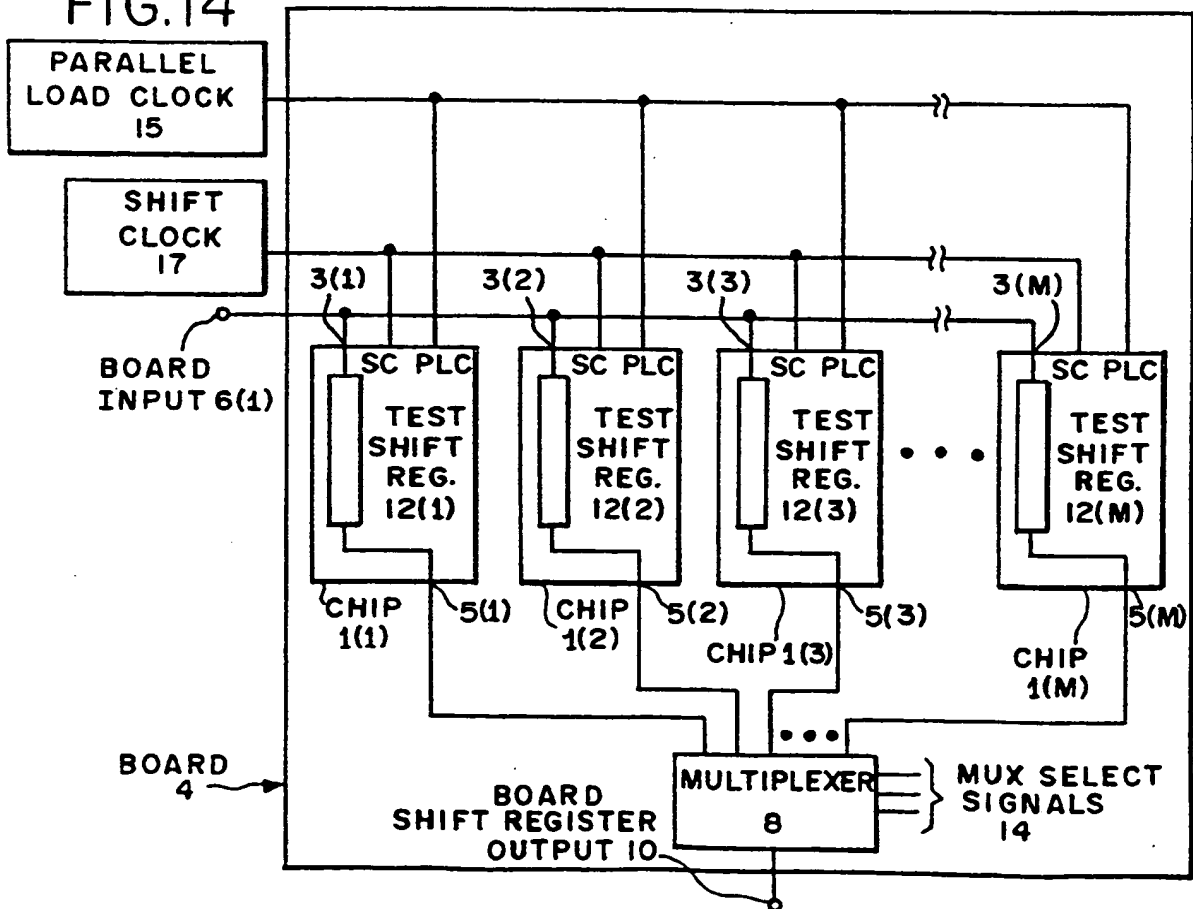


FIG.14



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FIG. 15

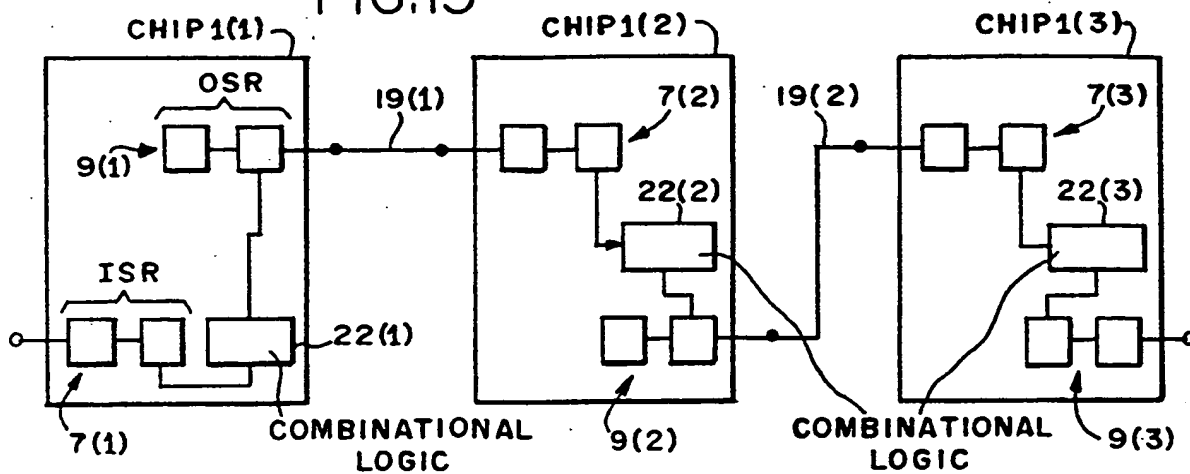


FIG. 16

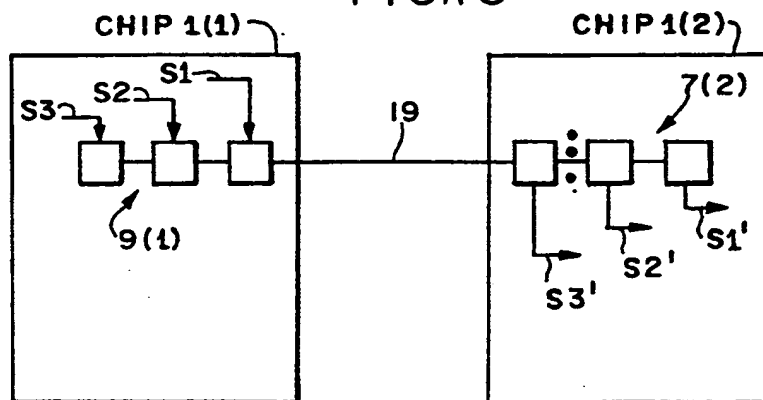
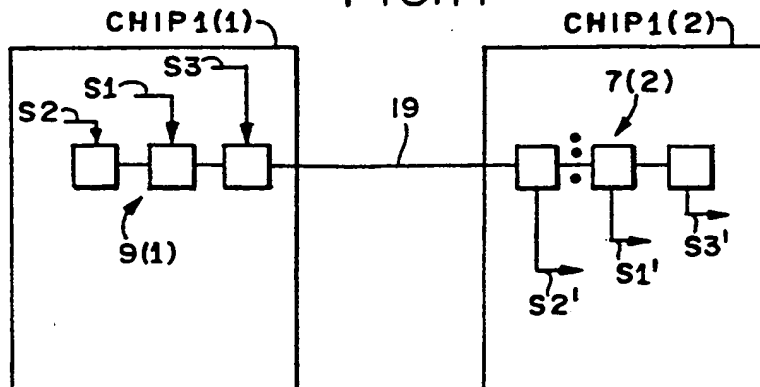
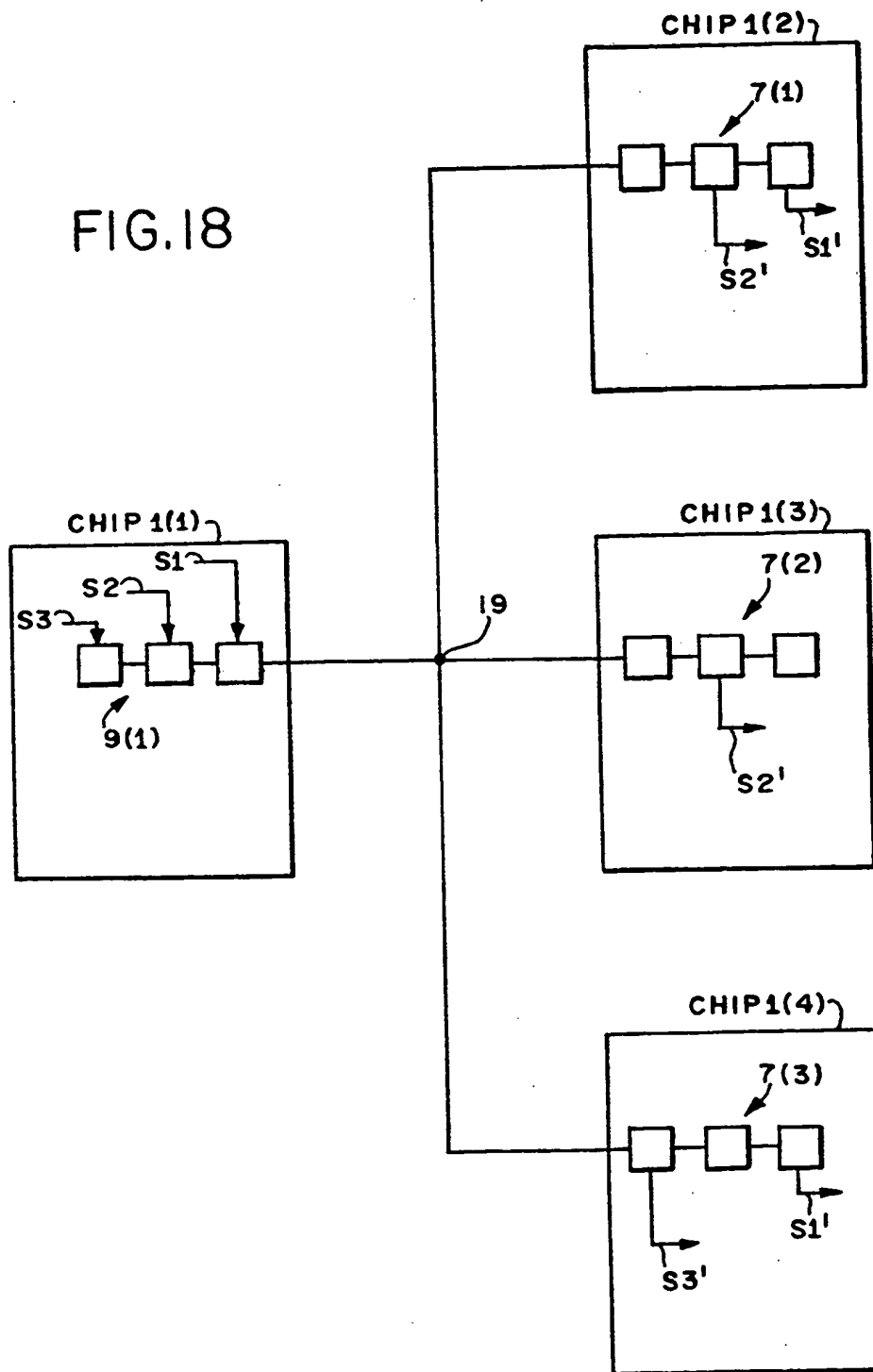


FIG. 17



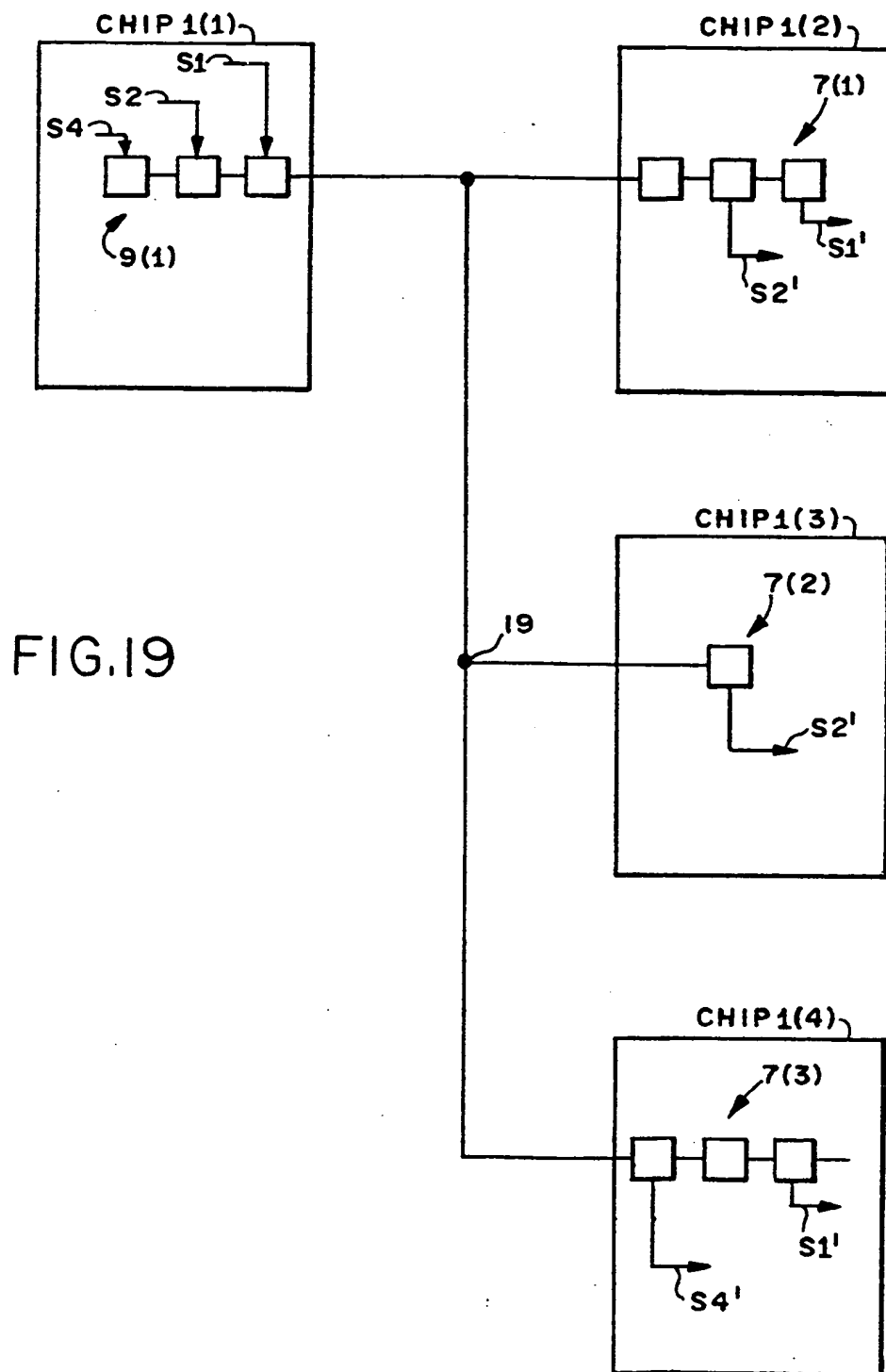
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FIG. 18





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FIG.20

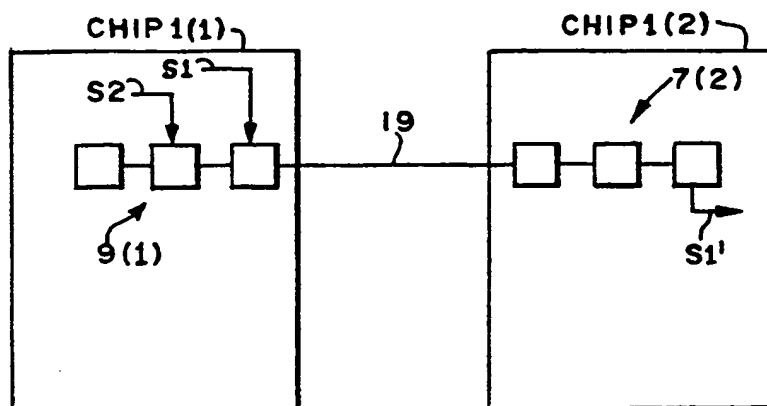


FIG.21

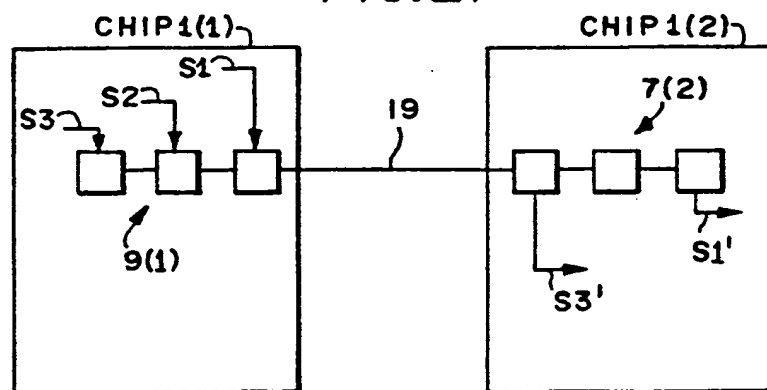
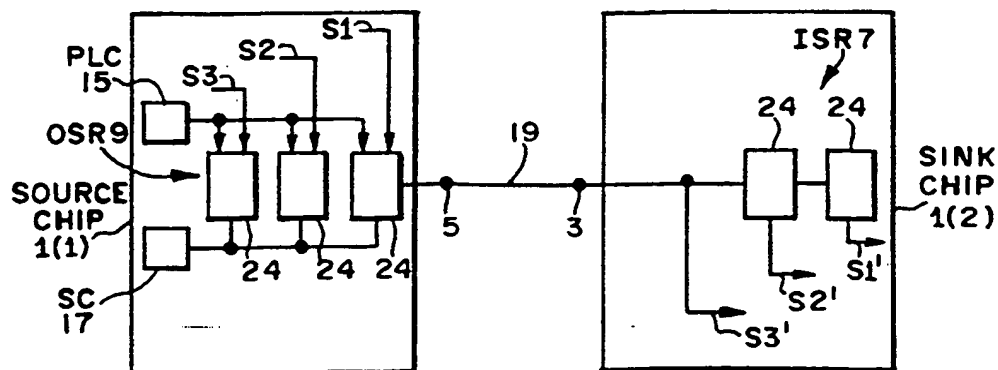


FIG.22



# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 92/07299

|   |   |                                     |
|---|---|-------------------------------------|
| <b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>   |   |                                     |
| According to International Patent Classification (IPC) or to both National Classification and IPC<br>Int.Cl. 5 H03K19/173; G06F1/22   |   |                                     |
| <b>II. FIELDS SEARCHED</b>  |   |                                     |
| Minimum Documentation Searched <sup>7</sup>   |   |                                     |
| Classification System   | Classification Symbols  |                                     |
| Int.Cl. 5   | H03K ; G06F   |                                     |
| Documentation Searched other than Minimum Documentation<br>to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>   |   |                                     |
|   |   |                                     |
| <b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>   |   |                                     |
| Category <sup>10</sup>  | Citation of Document, <sup>11</sup> with Indication, where appropriate, of the relevant passages <sup>12</sup>  | Relevant to Claim No. <sup>13</sup> |
| X   | MINI MICRO CONFERENCE RECORD May 1984, NEW YORK US<br>pages 1 - 6<br>STANLEY 'versatile serial protocol for a microcomputer-peripheral interface'<br>see the whole document | 1,2,7,<br>12,13,14                  |
| Y   | ---<br>see the whole document   | 3                                   |
| Y   | GB,A,2 164 769 (INTERNATIONAL STANDARD ELECTRIC CORPORATION)<br>26 March 1986   | 3                                   |
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| <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>10</sup> Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p> </div> </div> |   |                                     |
| <b>IV. CERTIFICATION</b>  |   |                                     |
| Date of the Actual Completion of the International Search   | Date of Mailing of this International Search Report   |                                     |
| 28 APRIL 1993   | 1 1. 05. 93   |                                     |
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